Completion Report

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MOVEMENTS AND DISTRIBUTIONS OF NORTHERN SQUAWFISH DOWNSTREAM OF LOWER SNAKE RIVER DAMS RELATIVE TO THE MIGRATION OF JUVENILE SALMONIDS

COMPLETION REPORT

Prepared by:

D. J. Isaak
and
T. C. Bjornn

Idaho Cooperative Fish and Wildlife Research Unit
University of Idaho
Moscow, ID

National Biological Service
Seattle National Fisheries Research Center

Acknowledgments

Abstract

Northern squawfish *Ptychocheilus oregonensis* movements were monitored downstream of two lower Snake River dams during the juvenile salmonid migrations of 1992 and 1993. During a high flow year in 1993, the abundance of squawfish in the tailrace of Lower Granite Dam peaked in July, after the majority of juveniles had moved past Lower Granite Dam, and peak abundance was inversely related to river discharge. Few squawfish moved into the tailrace of Ice Harbor Dam in 1993 because of the extended period of spill. Distributions of squawfish in the tailrace of Lower Granite Dam varied between and within years and shifted in response to changing prey densities, flow patterns, water temperature, and diel cycles, but fish consistently used low velocity habitats. Data from Ice Harbor Dam is less extensive, but squawfish distributions there appeared to be affected by changing flow patterns and fish used low velocity habitats. We believe the changes in distribution and abundance of squawfish in tailrace areas are evidence that predation on seaward migrating salmonids depends on the timing of migration and size and timing of runoff. Juvenile salmonids migrating in the spring and early summer will probably be less affected by squawfish predation in tailrace areas than salmon that migrate later in the summer.

Mobile tracking of squawfish at Lower Granite Dam did not reveal concentrations of fish downstream of an infrequently used juvenile bypass outfall, but several individuals were repeatedly found 30 m upstream from the bypass outfall, near a continuous discharge from a large pipe. Habituation by squawfish to the predictable pipe discharge suggests that predation could become a problem at the bypass outfall if it were regularly used to return juvenile migrants to the river. No squawfish were found during mobile tracking efforts near an ice and trash sluiceway outfall that many juvenile migrants used to pass Ice Harbor Dam. High water velocities probably excluded squawfish from the area around the sluiceway discharge, but this conclusion should be accepted with some skepticism because squawfish were not observed at night and electrical interference decreased sampling efficiency at this site.

Squawfish in the tailrace of Lower Granite Dam moved most actively during crepuscular periods (87 and 99 m/h), least actively immediately after each peak (29 and 41 m/h), and at a mid range during daylight hours (51 to 60 m/h). Chronology of squawfish activity as determined from autonomous fixed receivers near the juvenile bypass and ice and trash sluiceway outfalls corroborated this activity pattern. Behavioral variation was observed between and within squawfish during continual tracking efforts and in home range size and shape. Home range estimates within the tailrace of Lower Granite Dam ranged from 7,822 m2 to 188,163 m2 with an average of 70,185 m2.

The distribution of squawfish in Little Goose Reservoir varied seasonally as fish moved downstream into the reservoir during the fall of 1993. Downstream of Ice Harbor Dam, most squawfish held midway between the dam and the mouth of the Snake River until late June, when squawfish with transmitters moved down into the Columbia River.

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Introduction

There is evidence that predation by northern squawfish *Ptychocheilus oregonensis* on migrating juvenile salmonids is partially to blame for the decline of Snake River salmon stocks during the last three decades (Uremovich et al. 1980; Bentley and Dawley 1981; Rieman et al. 1991). For this reason, predation related research has been given high priority in the Columbia River Basin. This study was designed to provide insight into the predation process and was subcontracted to the Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho through the National Biological Service (formerly part of the U. S. Fish and Wildlife Service) as part of Bonneville Power Administration Project Number 82-003, "Significance of Predation and Development of Prey Protection Measures for Juvenile Salmonids in the Columbia and Snake River Reservoirs".

Many factors have played a role in the decline of Snake River salmon including overfishing, habitat degradation, interactions with hatchery fish, extended droughts, and changing ocean conditions, but hydroelectric development of the Columbia River Basin is cited as the single largest cause of reduced salmon runs by the Northwest Power Planning Council (1987). The construction of eight mainstem dams in the lower Snake and Columbia rivers changed a free-flowing river into a series of reservoirs that juvenile anadromous salmonids must migrate through on their way to the sea. Survival rates of smolts have decreased because of delayed migrations (Raymond 1968; Bentley and Raymond 1976; Raymond 1979), gas bubble disease from spill at dams (Ebel and Raymond 1976; Weitkamp and Katz 1980), mortality associated with passing through powerhouses (Schoeneman et al. 1961; Long et al. 1968), and predation (Ledgerwood et al. 1990; Rieman et al. 1991).

Losses of juvenile salmonids to predation in the mainstem of the Columbia River can be substantial (Poe et al. 1991; Rieman et al. 1991; Vigg et al. 1991). Rieman et al. (1991) estimated an annual loss of 2.7 million juvenile salmonids or 14% of all juvenile migrants entering John Day Reservoir from 1983 - 1986. Squawfish were responsible for 78% of the losses. Predation was especially intense in the tailrace of McNary Dam, where squawfish were 12 to 18 times more abundant than they were in the remainder of the reservoir (Beamesderfer and Rieman 1991). Other researchers have found squawfish predation to be a problem near dams (Long and Krema 1969; Uremovich et al. 1980; Bentley and Dawley 1981). The degree of squawfish predation should not be surprising given their abundance in the Columbia River system and their tendency to aggregate downstream of dams (Sims et al. 1978; Bentley and Dawley 1981; Bennett et al. 1983; Beamesderfer and Rieman 1991), where juvenile migrants are disoriented and stressed after passing the dam, making them more susceptible to predation (Congleton et al. 1984; Sigismondi and Weber 1988; Olla and Davis 1989; Mesa 1994).

To decrease mortality of smolts passing dams, the United States Army Corp of Engineers (USACOE) installed submersible traveling screens at most mainstem

hydroelectric projects. Submersible traveling screens extend into the turbine intakes and divert juvenile migrants into a bypass system that circumvents the powerhouse and leads to the tailrace area, where juveniles can be collected for transport to the lower Columbia River or discharged back to the river. However, survival of bypassed juveniles has rarely been evaluated. The only evaluation to date occurred at Bonneville Dam where survival of juveniles passing through the bypass system was lower than that of juveniles passing by the turbines (Ledgerwood et al. 1994). The investigators speculated that the lower survival associated with the bypass system was due to increased predation by squawfish near the juvenile bypass outfall.

The main goal of this research was to assess the movements of squawfish near two dams in the lower Snake River relative to the seaward migration of juvenile anadromous salmonids, with special emphasis on tailraces and areas near proposed or existing bypass outfalls. Specific objectives included: 1) monitoring the seasonal abundance of squawfish in tailrace areas, 2) quantifying the movements and distributions of squawfish in tailraces relative to changes in biotic and abiotic variables, and 3) monitoring the seasonal distribution of squawfish downstream of dams and tailrace areas.

LOWER GRANITE DAM STUDY

Study Area

Lower Granite Dam, completed in 1975 at river kilometer 175 on the Snake River in southeastern Washington was the final dam constructed as part of the Lower Snake River Project (Figure 1).
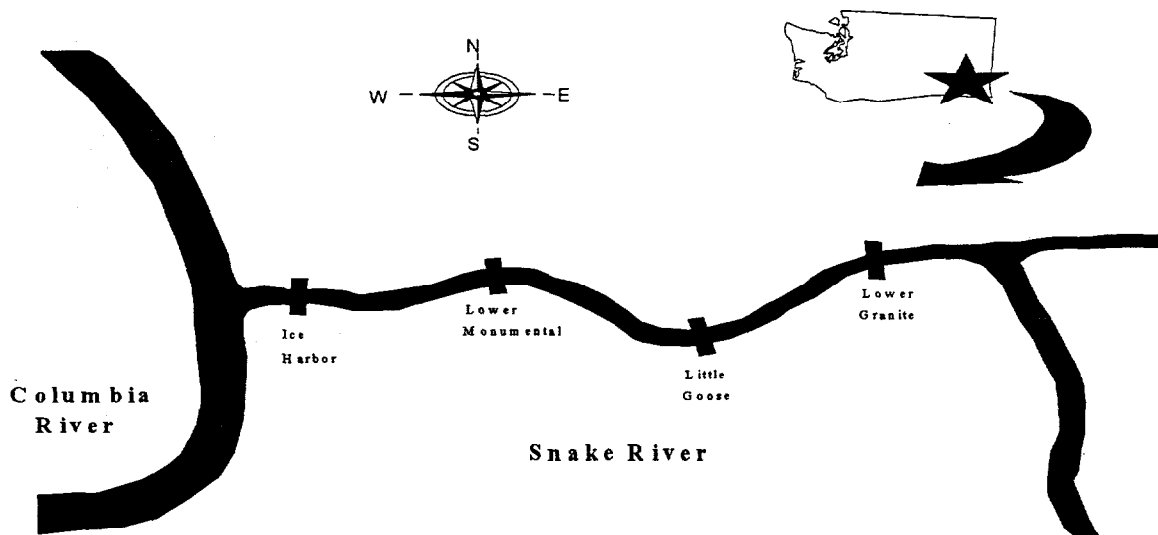
Figure 1. Four mainstem hydroelectric projects completed as part of the Lower Snake River Project in southeast Washington.

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Lower Granite Dam was chosen as a study site because it is the first encountered by most juvenile migrants leaving the Snake River basin during their seaward journey, and it has a juvenile bypass and collection system. Lower Granite Dam consists of a non-overflow embankment extending from the north shore, a navigational lock and spillway in mid-channel, and a powerhouse extending from the south shore (Figure 2). Hydraulic capacity of the powerhouse is 3,640 m^3/s and excess is spilled through up to eight tainter gates (USACOE, unpublished). Water velocities within the tailrace of Lower Granite Dam range from near zero to 2.7 m/s depending on river flow, discharge pattern, and position within the tailrace (Figure 3). Lock discharges occur periodically and create powerful upwellings of water near the southwest corner of the lock.
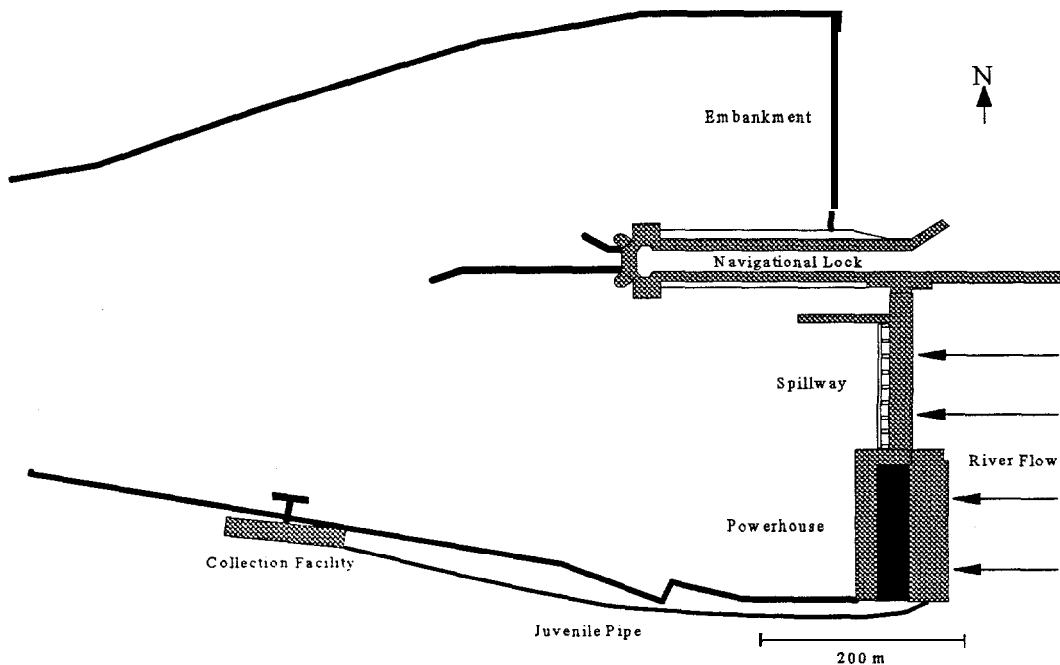
Figure 2. Tailrace of Lower Granite Dam on the lower Snake River in southeast Washington.

Migrating juvenile salmonids pass Lower Granite Dam via the spill, through the powerhouse, or the bypass system. When spill does not occur, screens divert 40 - 70 % of the juvenile migrants entering the turbine intakes into the bypass system (Swan et al. 1990), with the remainder passing by the turbines and into the tailrace of the dam (Figure 4). Diverted juveniles are carried through a pipe to the collection facility (Figure 2). Juveniles are separated from the water and detained in raceways before being returned to the river or loaded onto barges for transport to the Columbia River downstream from Bonneville Dam. Water used to carry the smolts to the collection facility is continuously discharged through a large pipe 30 m upstream from the barge dock (Figure 5). When juveniles were returned to the river, they normally passed through a pipe that hung down from the barge dock. Under emergency conditions, juveniles may be routed back to the river through the large pipe (Tim Wik, USACOE, personal communication).

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Flow pattern and velocitites during spill at Lower Granite Dam.

0 m/s

N

0 m/s

1.7 to 2.7 m/s

0.6 to 1.7 m/s
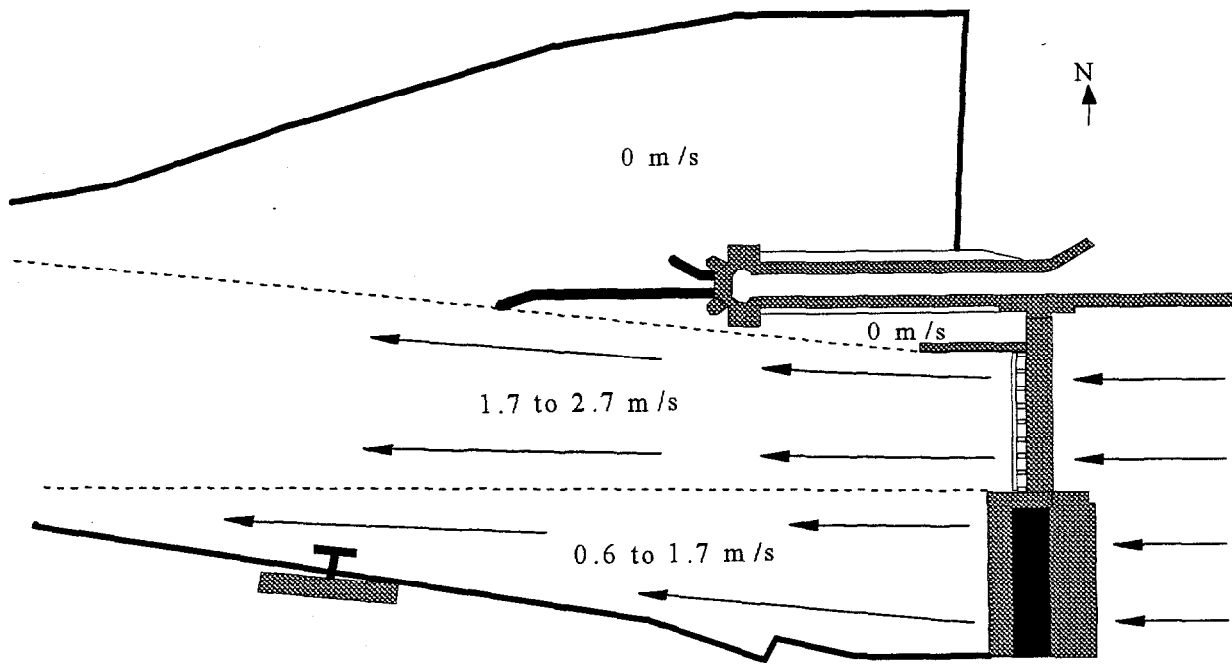
Flow pattern and velocities during no spill at Lower Granite Dam.

0 m/s

0 m/s

0.6 to 1.7 m/s
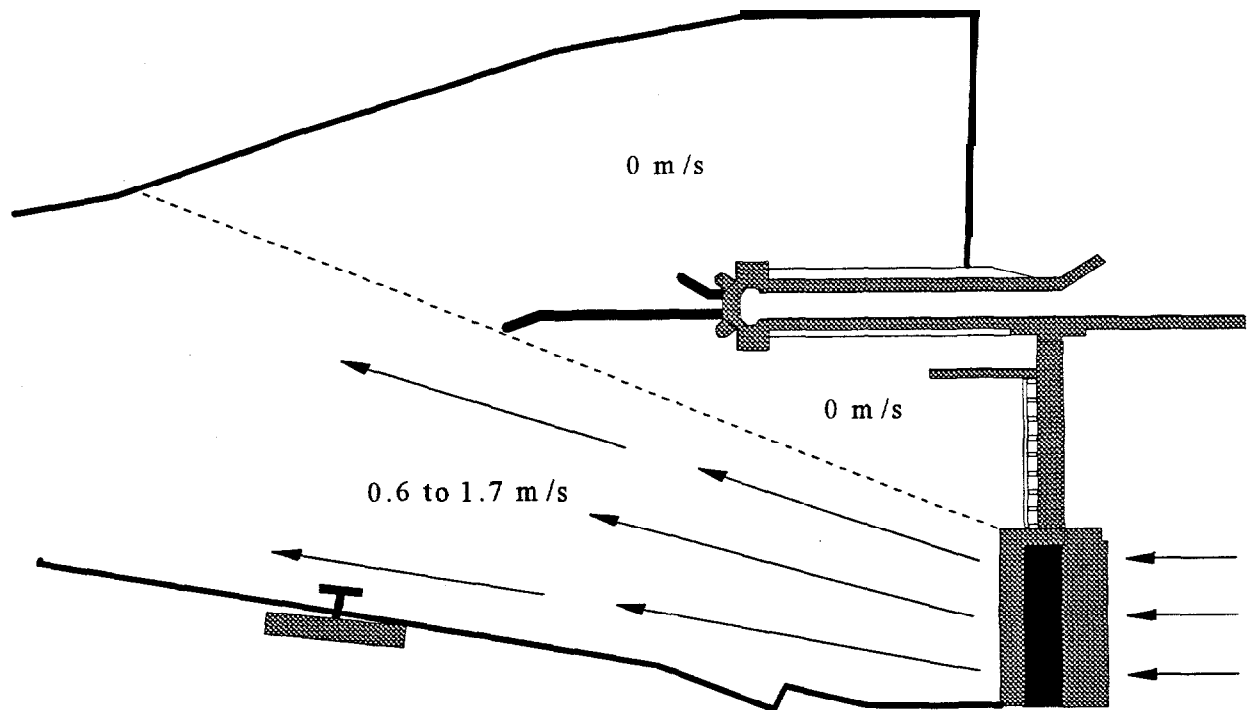
Figure 3. Flow patterns (arrows) and velocities within the tailrace of Lower Granite Dam during spill and no spill conditions.
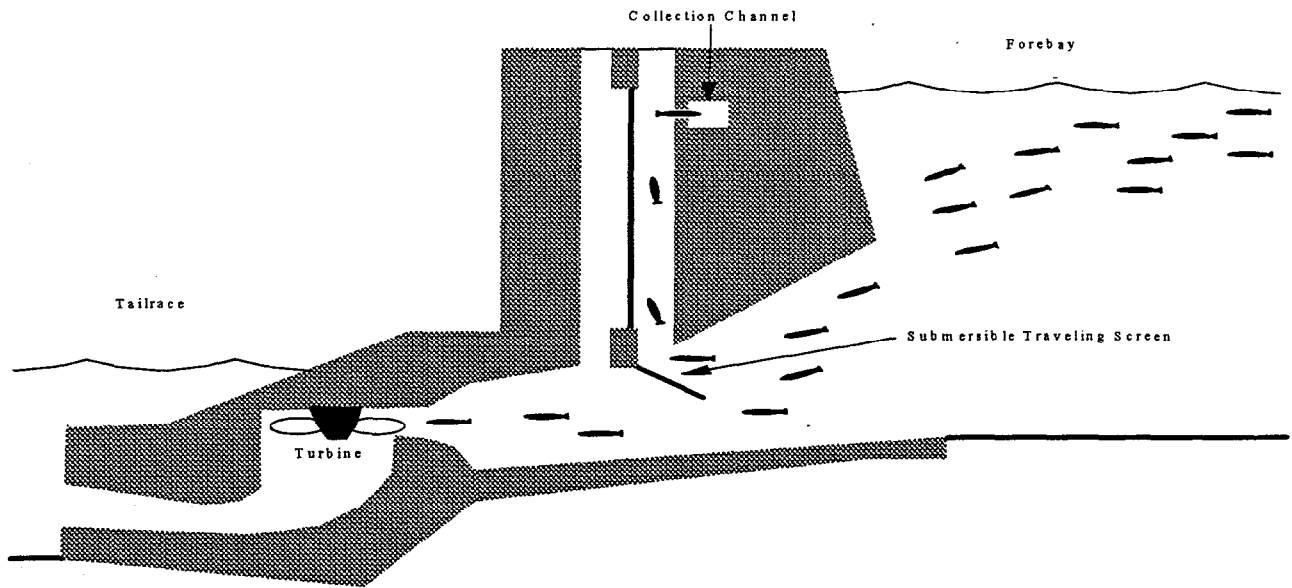
Figure 4. Cross-sectional view of the system used to divert migrating juvenile salmonids from turbine intakes at Lower Granite Dam.
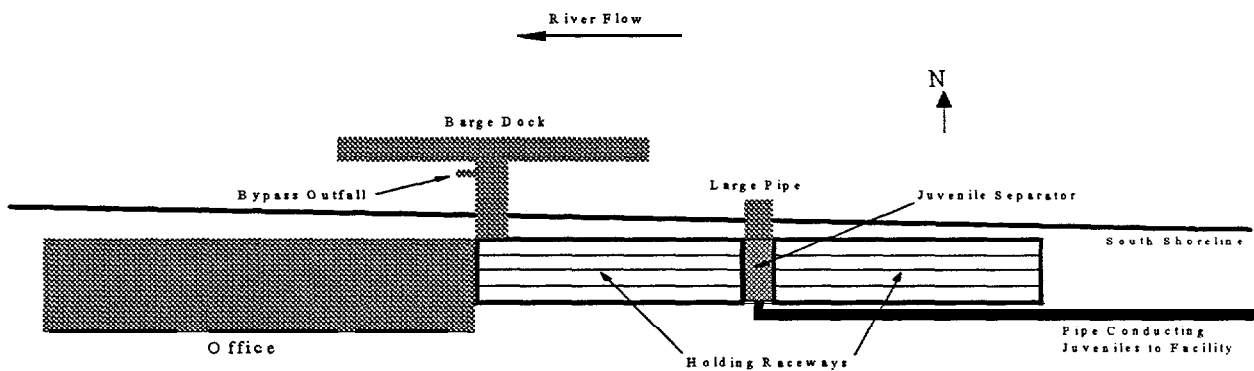
Figure 5. Schematic of the juvenile collection facility downstream of Lower Granite Dam.

During 1992, nearly seven million juveniles were collected at the Lower Granite collection facility; 6.8 million were transported and 0.1 million (nearly all on May 6) were bypassed back to the river (Ceballos et al. 1993). In 1993, eight million fish were collected, 7.6 million were transported, and 0.4 million (mostly on May 7, 8, and 10) were returned to-the river (Wik et al. 1994).

Three species of salmonids comprise the juvenile seaward migration in the lower Snake River; steelhead trout <u>Oncorhynchus</u> <u>mykiss,</u> chinook salmon <u>O.</u> <u>tschawytscha,</u> and sockeye salmon <u>O. nerka</u>. Chinook salmon are further divided into spring, summer, and fall runs based on the time adults enter the Columbia River. Spring and summer chinook salmon, sockeye salmon, and steelhead trout juveniles migrate seaward in April, May, and June as yearling and older fish. Fall chinook salmon migrate as subyearlings in late June, July, and August. Juvenile migrations at Lower Granite Dam in 1992 and 1993 were made up of 28% spring/summer chinook salmon, 72% steelhead trout, and less than 1% sockeye and fall chinook salmon (Ceballos et al. 1993; Wik 1994).

River conditions varied considerably between the two study years at Lower Granite Dam. Nineteen ninety-two was a drought year with warmer than normal water temperatures and a January to July discharge that was 42% of the 30-year average (Fish Passage Center 1993). Discharge was 90% of normal in 1993, spill occurred for several weeks at Lower Granite Dam, and water temperatures were cooler than in 1992 (Fish Passage Center 1994; USACOE, unpublished; Figure 6).

Lower Granite Dam lies at the head of Little Goose Reservoir, which was formed in 1971 with the completion of Little Goose Dam. At normal operating pool, Little Goose Reservoir is at elevation 194 m, with a surface area of 4,057 hectares, and a volume of 6.98 x 10^8 m^3. Depth and width of the reservoir gradually increases downstream from Lower Granite Dam, with widths ranging from 250 m to 1,432 m with a mean of 518 m, depths vary from 3 m to 41 m with a mean of 17 m (Bennett et al. 1983). No major tributaries enter the reservoir over its 60 km length, and water temperatures annually range between 4°C and 23°C, with February minima and August maxima. The reservoir has been classified as mesotrophic and polymictic, thermal statification occurs rarely and is most likely in late summer during decreased flows (Funk et al. 1985). Surrounding physical habitat is characterized by steep valley walls with frequent basalt outcroppings.

Methods

Movements and abundance of squawfish near Lower Granite Dam was assessed by tracking relatively large fish outfitted with radio-transmitters. Squawfish were collected downstream of Lower Granite Dam with electrofishing boats operated parallel to shore. Two netters in the bow of the boat and one in the rear dipped fish that were stunned with a pulsed DC current of 3.0 - 3.5 A and 400 V. Study specimens were selected so that transmitter weight did not exceed 2% of the fish weight (Winter 1983).

After collection, fish were anesthetized in a 100 mg/L solution of tricaine methanesulfonate and a 150 MHz radio-transmitter (part number CFRT-3B; Lotek
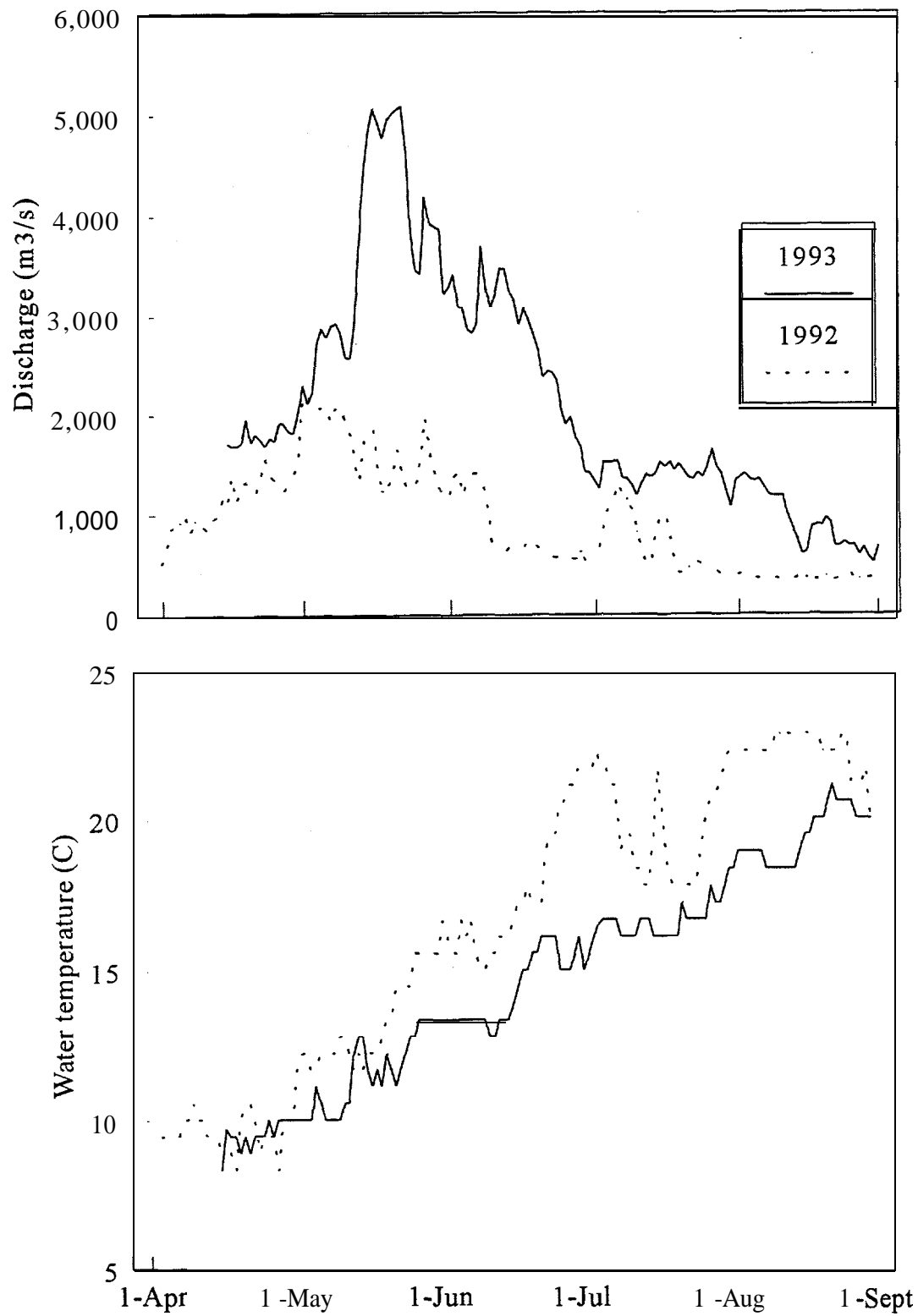
Figure 6. River discharge and water temperatures at Lower Granite Dam during 1992 and 1993.

Engineering', Ontario, Canada) was surgically implanted in their body cavities. Each transmitter was cylindrical in shape (14 x 45 mm), had a 46 cm, 16-gauge wire antenna, weighed 10.6 g in air, transmitted a 3.5 V signal, and had a battery life of nine months. Surgical implantation of the transmitter in the body cavity was performed using a technique similar to the shielded-needle methodology developed by Ross and Kleiner (1982). Instead of shielding the needle, a nasal speculum was used to lift the abdomen wall away from the viscera, thereby providing room in the coelom to pass the needle from its insertion posterior of the pelvic girdle through to the anterior incision. Fish were released immediately after the operation to reduce holding stress (Hart and Summerfelt 1975).

A total of 140 squawfish were outfitted with radio-transmitters and released during the two years of this study, 77 in 1992 and 63 in 1993. Fish ranged in size from 339 mm to 575 mm with a mean of 412 mm (SD = 51 mm; Appendix A). Late arrivals of equipment postponed tagging until late April in 1992, but squawfish were abundant and easily captured in the tailrace of Lower Granite Dam. As a result, 71 of 77 fish were captured, implanted with radio-transmitters, and released in the tailrace. The remaining six fish were captured and released 7 km downstream.

Collection efforts began in early April of 1993 and most squawfish were captured 0.8 to 5 km downstream of Lower Granite Dam. The fish were taken to Boyer Marina (2.8 km downstream from Lower Granite Dam), implanted with transmitters, and released at the marina. All fish volitionally left the marina and many were subsequently relocated in areas similar to those from which they had been captured. Fifty-five of the 63 squaw-fish implanted with transmitters in 1993 were released in Boyer Marina, the final eight fish were captured in the tailrace of the dam on June 12, implanted with transmitters, and released there.

Data collection techniques. - Squawfish were relocated by triangulation, homing on their positions with a boat, and at fixed receiving sites, outfitted with autoscanning, datalogging telemetry receivers (part number SRX-400, Lotek Engineering, Ontario, Canada). Squawfish in the tailrace of Lower Granite Dam were located by triangulation during 1992 and during periods of spill in 1993. Two simultaneous bearings were taken with nine-element Yagi antennas (part number PLC - 10, Cushcraft Corp., Manchester, New Hampshire) from triangulation stations located around the tailrace of the dam (Figure 7). Adjacent triangulation stations were rotated through in a systematic manner to ensure complete coverage of the tailrace. Antenna bearing error (mean = -1.5°; SD = 10.2°; n = 30) was calculated by having a naive investigator take bearings on transmitters placed in known positions at the study site.

During 1993, a 6-m long jetboat equipped with a six-element Yagi antenna (part number PLC - 6, Cushcraft Corp., Manchester, New Hampshire), telemetry receiver,

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[1]Reference to trade names does not imply endorsement by the University of Idaho or Bonneville Power Administration.

and a global positioning receiver (part number 16787-20, Trimbel Navigation, Sunnyvale, California) was used to locate squawfish and record their positions. Post-processing software (Pfinder 2.31, Trimbel Navigation, Sunnyvale, California) and differential correction files were later used to remove errors from global positioning files and obtain 2 to 5 m accuracy.

Triangulation Station
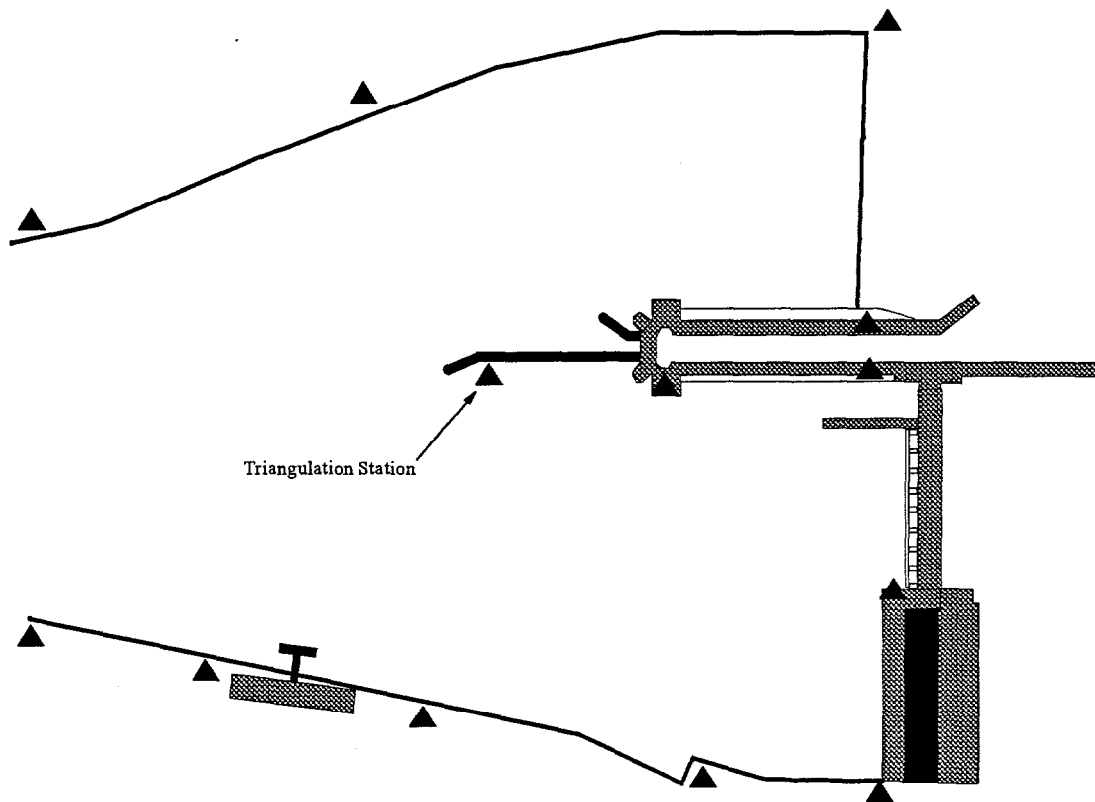
Figure 7. Triangulation stations used to determine squawfish positions within the tailrace of Lower Granite Dam during 1992 and during periods of spill in 1993.

Movements of squawfish into areas adjacent to the juvenile collection facility at Lower Granite Dam were recorded on SRX-400 receivers. During 1992 and initially in 1993, the receiver monitored three underwater coaxial antennas suspended from the barge dock adjacent to the collection facility. Underwater antennas were replaced with two five-element Yagi antennas in June of 1993 after high flows in late May damaged the underwater antennas.

Squawfish abundance. - The number of transmitter-equipped squawfish present in the tailrace of Lower Granite Dam was monitored in 1993 to determine when abundances were highest relative to juvenile passage indices and river discharge. Only fish (n = 40) released within Boyer Marina before the inception of the juvenile migration were considered in these calculations. The tailrace of Lower Granite Dam was searched approximately three times a week during the juvenile migration to locate the transmitter-equipped squawfish that had moved upstream to the dam. The

proportion of the first 40 fish released that was present in the tailrace at a given time was calculated as:

$$(A - B) / (40 - C - D) \qquad\qquad (1)$$

where:

    A = number of transmitter-equipped squawfish in tailrace,

    B = number of transmitter-equipped squawfish in tailrace that were released after inception of juvenile migration,

    C = number of transmitter-equipped squawfish recovered in the fishery,

    D = number of transmitter-equipped squawfish dead from surgical or natural causes.

A daily migrational index for each species of juvenile salmonid migrating past Lower Granite Dam was derived from daily collections at the juvenile collection facility (Ceballos et al. 1993; Wik et al. 1994). The migrational index corrected for the number of juvenile salmonids that pass a dam through the spill by dividing the daily collection total by the proportion of total river discharge that passes through the powerhouse. River discharge data for 1993 were supplied by the USACOE.

Squawfish distribution and habitat use. - The distribution of squawfish in the tailrace of Lower Granite Dam over time was monitored during the juvenile migration to assess possible shifts that may have resulted from changing biotic or abiotic variables. Squawfish in the tailrace of Lower Granite Dam were located approximately twice a week in 1992 and three times a week in 1993 (Table 1). Flow conditions within the tailrace did not vary widely in 1992 and squawfish observations were stratified into early and late periods based on timing of the juvenile migrantion and a distributional shift that occurred in the squawfish population once water temperatures reached 16%. The occurrence of higher flows and spill in 1993 precluded using a similar stratification scheme and observations were divided into prespill, spill, and postspill periods. Half the sampling effort in 1993 was conducted during the day (1100 to 1500) and half during the night (2300 to 0300) to facilitate day and night comparisons. Observations of fish locations and movements within each period were assigned to one of four cells within the tailrace (Figure 8), boundaries of which were based largely on prevailing flow characteristics in the tailrace. The boundary around the juvenile collection facility was established because this was an area of special interest. Distributional differences between periods were tested using heterogeneity G-tests (Sokal and Rohlf 1981) and an $\alpha = 0.05$.

Table 1. Sampling schedule for squawfish study in Lower Granite tailrace and Little Goose Reservoir durina 1992 and 1993.

		1992		1993			
	Week	Tailrace distribution	Fixed receiver	Tailrace distribution	Continual tracking	Fixed receiver	Reservoir distribution
April	1					X	
	2					X	
	3			X		X	
	4					X	
May	1	X		X		X	
	2					X	
	3	X		X		X	
	4	X		X			
June	1	X		X	X		
	2	X	X	X	X		
	3	X	X	X		X	
	4	X	X	X	X		X
July	1	X	X	X			
	2		X	X	X	X	
	3		X	X	X	X	X
	4		X	X	X	X	
August	1		X	X	X	X	
	2			X		X	X
	3			X		X	
	4					X	
September	1					X	
	2					X	
	3			X		X	X
	4					X	
October	1					X	
	2					X	
	3					X	
	4			X		X	
November	1					X	
	2					X	
	3			X		X	X
	4					X	

Figure 8. Cell boundaries used to partition squawfish observations in the tailrace of Lower Granite Dam for statistical analysis.

At Lower Granite Dam, the preference or avoidance of individual cells within each period was tested using a methodology developed by Neu et al. (1974). Within each period, a chi-square test assessed whether usage of individual cells was occurring in proportion to their availability, considering all cells simultaneously. If this hypothesis was rejected, Bonferroni z-statistics (Miller 1981) were used to construct confidence intervals that allowed determination of which individual cells were used more or less frequently than expected. Experimentwise error rates were controlled at alpha = 0.05 by partitioning the significance level by the number of confidence intervals constructed.

Water velocity use. -Water velocities were measured at squawfish positions and random positions in the tailrace of Lower Granite Dam to determine whether squawfish selected certain water velocities. Twice while sampling the distribution of squawfish (June 26 and July 27), water velocities were taken 1 m below the surface using a flowmeter (part number 2000, Marsh-McBirney, Inc., Frederick, Maryland). Data were nonnormally distributed and zeros were prevalent, therefore a two-way median test (Steel and Torrie 1980) was used to initially treat the data before it was summarized in a 2 x 2 table which was then tested for homogeneity using a heterogeneity G-test (Sokal and Rohlf 1981).

Squawfish Activity Pattern. - Movements of individual squawfish were monitored to determine diel activity patterns in the tailrace of Lower Granite Dam. On seven occasions in 1993 (Table I), a boat was used to monitor individual-fish for extended periods of time. During each sampling period, five fish were selected at random from the population of squawfish with transmitters in the tailrace and each fish was then relocated approximately every hour for up to 24 hours. Movement rates were calculated by dividing the straight line distance between two consecutive locations by the intervening time interval. A day was broken into 12 two-hour periods and each movement rate estimate was assigned to the interval in which its midpoint fell. Data lacked normality and were transformed into Savage scores before a one-way ANOVA was calculated (SAS Institute 1988). A posteriori pairwise multiple comparisons were conducted using Fisher's LSD.

Data from the fixed receiver were used to estimate the chronology of squawfish activity near the juvenile collection facility and the sluiceway. The area near the juvenile bypass was monitored intermittently in 1992 and almost continuously in 1993 (Table 1). The date, time, antenna, signal strength, and individual fish codes were recorded on the receivers whenever a transmitter-equipped squawfish moved into the reception range of an antenna. Antenna reception range was standardized by adjusting receiver gain whenever antenna configurations were changed. Reception range of underwater antennas extended approximately 10 m in all directions from the ends of the barge dock. The receivers recorded multiple records on an individual fish if it remained near an antenna for an extended period of time. Activity over time was estimated by using one observation per fish per hour to avoid biasing the sample towards those fish which lingered near antennas. The distribution of these observations was tested for uniformity using a Watson EDF test (Stephens 1974). At Lower Granite Dam, squaw-fish observations collected after the replacement of the underwater antennas with Yagi antennas were tested with a sign test (Daniels 1990) to determine whether fish were more likely to be found near one of the two antennas.

Squawfish home ranges. - Home range estimates for the postspill period were calculated for squawfish within the tailrace of Lower Granite Dam in 1993 if at least 25 observations were acquired on an individual during the course of routine distributional sampling. Home ranges were calculated using a nonparametric kernel estimation program that displays the home range in the form of a three-dimensional probability density function (Worten 1989; Garton, unpublished program). The program created home ranges regardless of the land-water interface, to adjust for this and provide more realistic home range estimates, probabilities in land areas were reset to zero, the density function rescaled to one, and the new home range plotted. The area circumscribed by the 90% contour was chosen as the home range estimate.

Disfribufion in reservoir. - The distribution of squawfish with transmitters in Little Goose Reservoir was monitored on five occasions from June 26 to November 20, 1993 (Table 1) to assess seasonal shifts. During a survey, the jetboat was driven down

the center of the river as the six-element Yagi antenna was alternately pointed at each shore. In Little Goose Reservoir, this procedure was followed from the tailrace of Lower Granite Dam to river km 150 where the reservoir became too wide to efficiently locate fish. The boat was then driven near one shoreline to Little Goose Dam and the other shoreline on the return trip. Distributions were compared by assigning squawfish observations to the Lower Granite tailrace, upper, middle, or lower third of Little Goose reservoir. The homogeneity of all distributions was tested simultaneously using a heterogeneity G-test, this was followed by pair-wise G comparisons (Sokal and Rohlf 1981). Experimentwise error rate was controlled at alpha = 0.05 during pair-wise comparisons by adjusting the probability level for the number of comparisons made.

Results

High transmitter failure rates in 1992 limited the amount of data gathered at Lower Granite Dam that year. Most of the results and conclusions which follow are based on data gathered in 1993 on squawfish in the Lower Granite Dam tailrace and Little Goose Reservoir.

Squawfish abundance. - The abundance of squawfish with transmitters in the tailrace of Lower Granite Dam during 1993 appeared to be inversely related to river discharge during peak periods of juvenile migrations. Squawfish numbers peaked early in May as did the number of migrating juvenile steelhead trout and spring and summer chinook salmon (Figure 9). Squawfish numbers then declined as river discharge increased. A second, larger peak in abundance of squawfish with transmitters began in mid-June after spill had ceased and river discharge declined. The peak migration of sockeye salmon coincided with the peak in the hydrograph and decreased abundance of squawfish in the tailrace (Figure 9). Fall chinook salmon migrated during July and August in 1993, under low-flow conditions, and when the largest number squawfish with transmitters was present in the tailrace (Figure 9).

Squawfish distribution and habitat use. - Fifty-five different squawfish were observed a total of 237 times in the tailrace of Lower Granite Dam during the seaward migration of salmonids 1992. Squawfish were most frequently found in the slackwater of the spilling basin (cell 2) with no spill in 1992, but were also regularly located in flowing water (cells 3 and 4) downstream from the powerhouse discharge (Figure 10). The distribution of squawfish differed significantly between early and late periods (GH = 30.80, p < 0.01; Figure 11). Squawfish with transmitters were often found north of the navigation lock (cell 1) during the early period, but were rarely observed in that area during the late period.

The initial null hypothesis of the use-availability analysis, that cells were used in
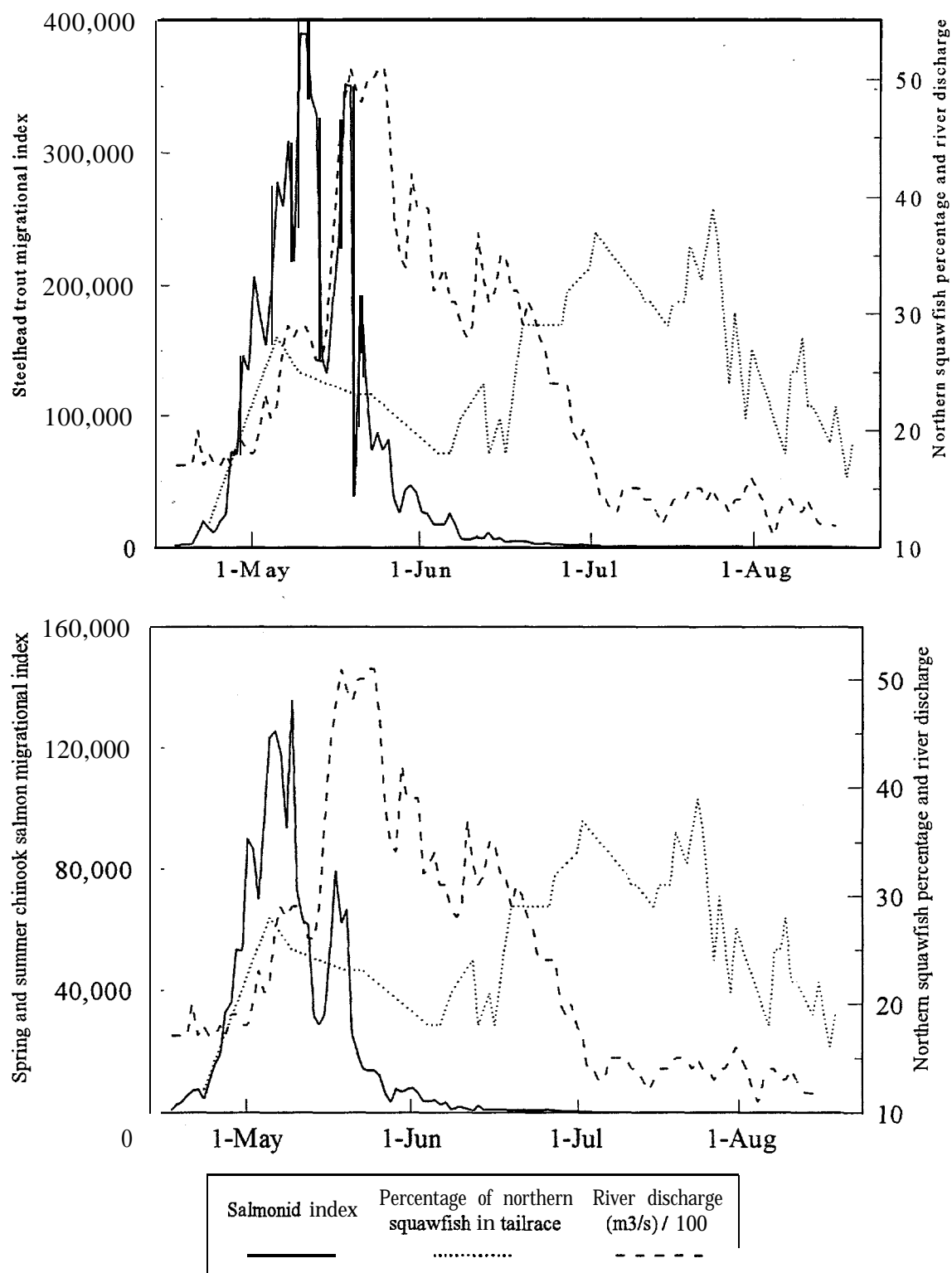
Figure 9. Comparisons of juvenile salmonid migrational indices, river discharge, and percentage of transmitter-equipped squawfish found in the tailrace of Lower Granite Dam during 1993.

Early period (109 observations; May 2 to May 29)
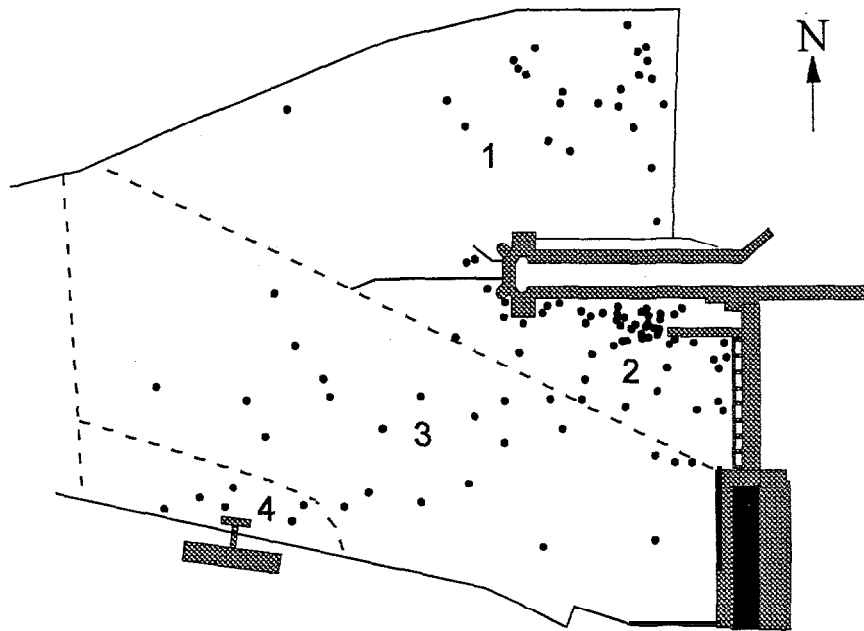
Late period (128 observations; June 6 to July 7)

Figure 10. Distributions of squawfish in the tailrace of Lower Granite Dam during the juvenile salmonid migration of 1992 in the lower Snake River.

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Figure 11. Comparison between early and late distributions of squawfish in the tailrace of Lower Granite Dam in 1992. Bars with letters differ significantly from their counterpart (P < 0.05). Overall distributions are significantly different (P < 0.05).

proportion to their availability, considering all cells simultaneously, was rejected for both periods (early χ^2 = 173.68, p < 0.01; late χ^2 = 391.67, p < 0.01; Table 2). Based on Bonferroni confidence intervals, we concluded that cell 2 was used more than would be expected by random chance during both early and late periods. Cell 3 was underutilized in proportion to its availability during early and late periods, and cells 1 and 4 were underutilized during the late period.

During the juvenile outmigration of 1993, 49 different squawfish were located 531 times to assess their distribution. Prespill, spill, and postspill distributions differed significantly (G_H = 149.48, p < 0.01; Figures 12 and 13). During the prespill period, 91% of the squawfish with transmitters were found in the area north of the navigation lock (cell 1) or in the spillway stilling basin (cell 2). During the spill period, 71% of the squawfish located were in cell 1. With cessation of spill, squawfish shifted from cell 1 north of the navigation lock to cells 2, 3, and 4. The null hypothesis of use in proportion to the availability of a cell was rejected for each of the time periods (prespill χ^2 = 43.32, p < 0.01; spill χ^2 = 43.24, p < 0.01; postspill χ^2 = 1,423.60, p < 0.01; Table 3). Similar to 1992, squawfish were not as abundant as expected in the area of powerhouse discharge (cell 3) during all periods and the spillway stilling basin (cell 2)

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was a preferred area except during spill. The greatest variability in use occurred in the area north of the navigation lock (cell I), where squawfish use was in proportion to its availability during the prespill period, higher than expected during spill, and lower than expected after spill. Annual comparisons are unexact because of differing stratification schemes, but it is interesting to note that proportions of observations in each cell during the 1993 postspill and 1992 late strata were nearly identical (Tables 2 and 3).

Table 2. Use-availability analysis **total area** of squawfish observations within the tailrace of Lower Granite Dam during early and late periods in 1992.

Cell	Observed	Expected	χ	Percent of observations	Area (m^2)	Percent of total area	Bonferonni confidence interval
				Early			
1	26	34.23	1.98	0.239	114,782	0.314	$0.127 \leq p_1 \leq 0.351$
2	53	11.34	153.13	0.486	38,074	0.104	$0.355 \leq p_2 \leq 0.617^*$
3	24	56.03	18.31	0.220	187,760	0.514	$0.111 \leq p3 \leq 0.329^*$
4	6	7.41	0.27	0.055	24,791	0.068	$0 \leq p_4 \leq 0.115$
Total	109	109	173.68		365,409		
				Late			
1	3	40.19	34.42	0.023	114,782	0.314	$0 \leq p_1 \leq 0.059^*$
2	81	13.31	344.18	0.633	38,074	0.104	$0.516 \leq p_2 \leq 0.75^*$
3	41	65.79	9.34	0.320	187,760	0.514	$0.207 \leq p_3 \leq 0.433^*$
4	3	8.70	3.74	0.023	24,791	0.068	$0 < p_4 < 0.059^*$
Total	128	128	391.67		365,409		

* = significance ascribed if confidence interval does not include the percentage of the total area of the respective cell

Forty-three different squawfish were observed 466 times during the postspill period in 1993. Observations during this period were partitioned into their day and night components and the two distributions were tested for heterogeneity (Figure 14). Squawfish with transmitters dispersed from cell 2 into cells 3 and 4 at night leading to significant differences (G_H = 12.99, p < 0.01; Figure 15) in day versus night distributions. Use was not found to be proportional to availability in either of the diel periods (day χ^2 = 900.16, p < 0.01; night χ^2 = 544.05, p < 0.01; Table 4). The Bonferroni confidence intervals suggest that a significant change in use occurred only in the area near the juvenile facility (cell 4), which was selected against during the day period and used in proportion to its availability at night. The number of squawfish located during day versus the night during prespill and spill periods in 1993 precluded testing for differences between day and night distributions within each period.

Prespill period (22 observations; April 21 to May 7)

Spill period (43 observations; May 17 to June 5)

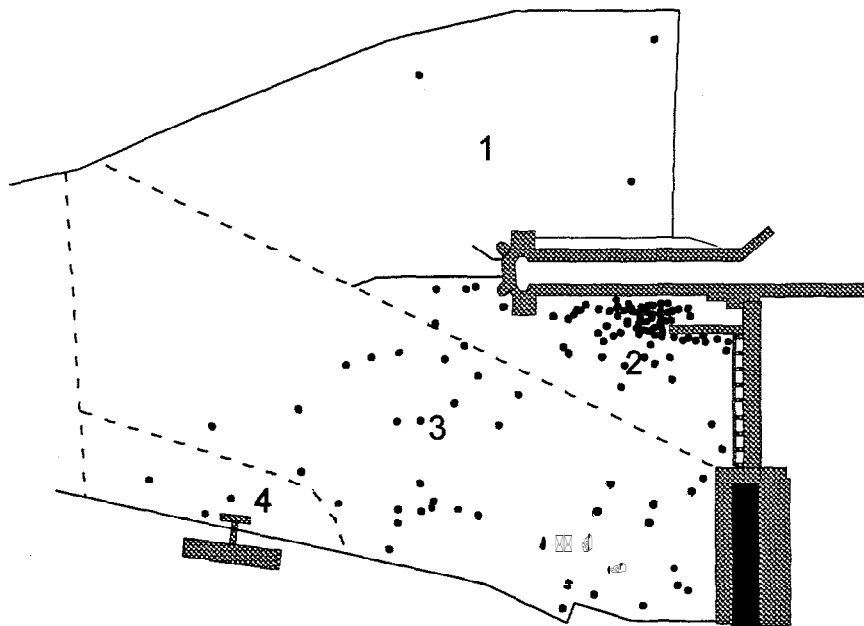Postspill period (466 observations; June 9 to August 20)
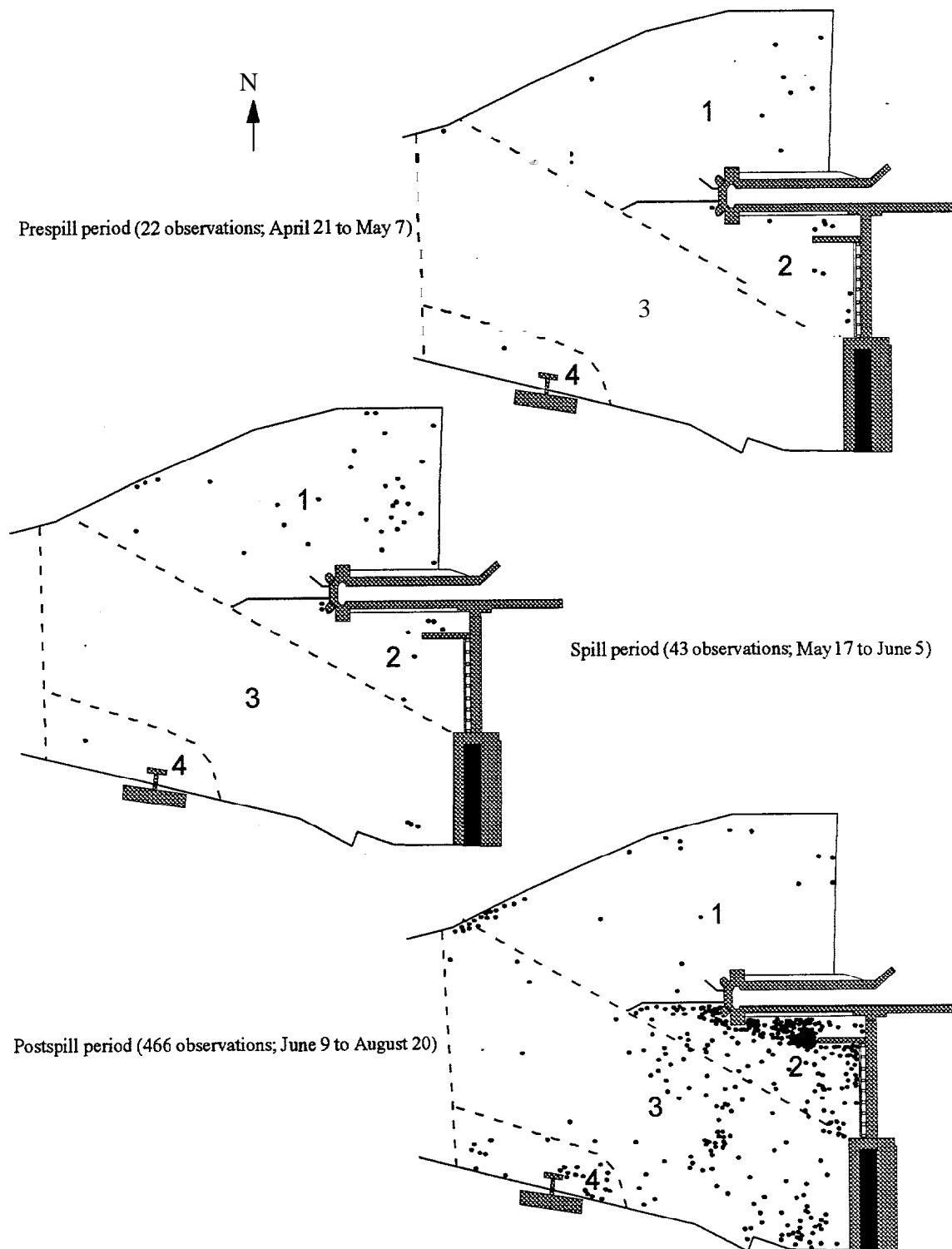
Figure 12. Distributions of squawfish in the tailrace of Lower Granite Dam during the juvenile salmonid migration of 1993 in the lower Snake River.
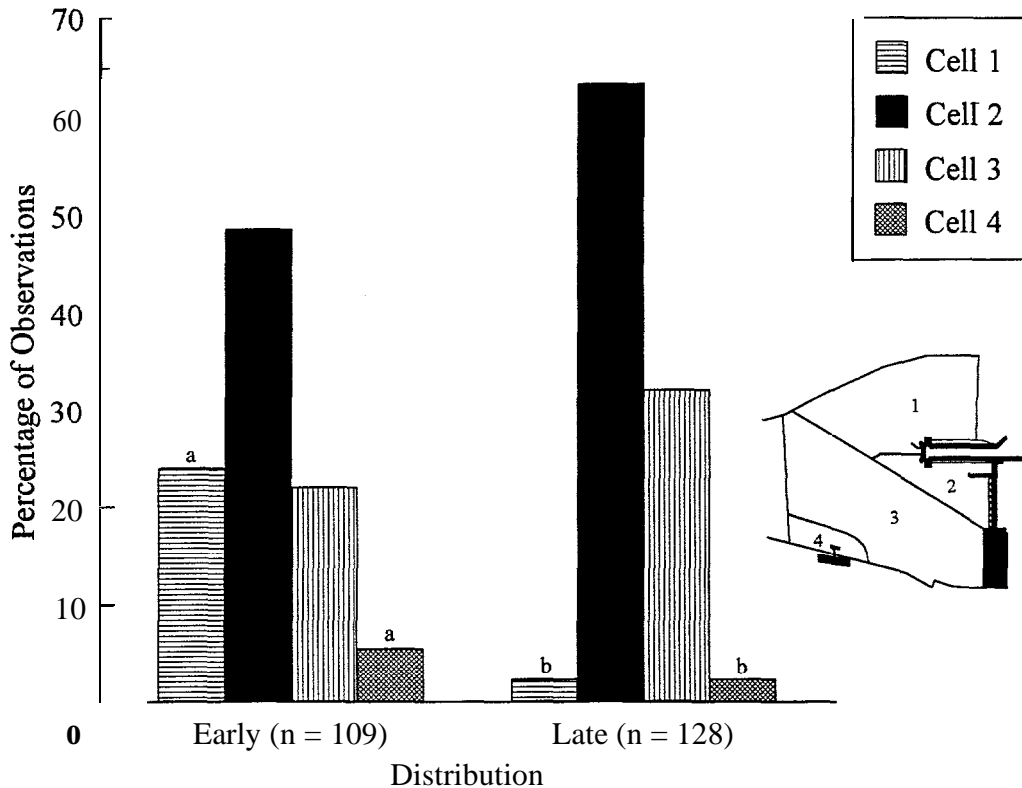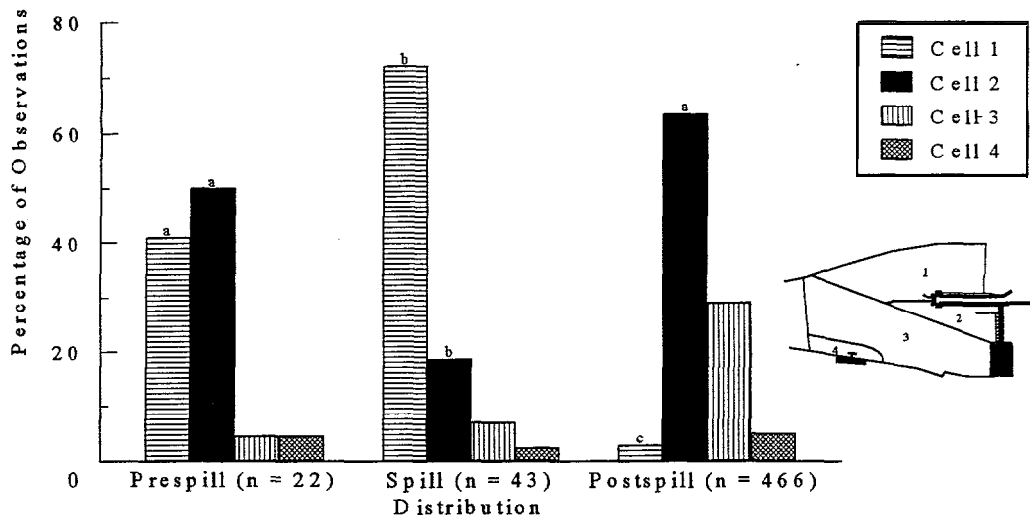
Figure 13. Comparison between prespill, spill, and postspill distributions of squawfish in the tailrace of Lower Granite Dam in 1993. Bars with letters differ significantly from their counterparts (P < 0.05).

Table 3. Use-availability analysis of squawfish observations within the tailrace of Lower Granite Dam during prespill, spill, and postspill periods in 1993.

Cell	Observed	Expected	χ^2	Percent of observations	Area (m^2)	Percent of total area	Bonferonni confidence interval
				Prespill			
1	9	6.91	0.63	0.409	114,782	0.314	$0.122 \leq p_1 \leq 0.696$
2	11	2.29	33.13	0.500	38,074	0.104	$0.208 \leq p_2 \leq 0.792$*
3	1	11.31	9.40	0,045	187,760	0.514	$0 \leq p_3 \leq 0.166$*
4	1	1.50	0.17	0.045	24,791	0.068	$0 \leq p_4 \leq 0.166$
Total	22	22	43.32		365,409		
				Spill			
1	31	13.50	22.68	0.721	114,782	0.314	$0.534 \leq p_1 \leq 0.908$*
2	8	4.47	2.78	0.186	38,074	0.104	$0.023 \leq p_2 \leq 0.349$
3	3	22.10	16.51	0.070	187,760	0.514	$0 \leq p_3 \leq 0.177$*
4	1	2.92	1.27	0.023	24,791	0.068	$0 \leq p_4 \leq 0.086$
Total	43	43	43.24		365,409		
				Postspill			
1	13	146.32	121.48	0.028	114,782	0.314	$0.007 \leq p_1 \leq 0.049$*
2	295	48.46	1254.13	0.633	38,074	0.104	$0.572 \leq p_2 \leq 0.694$*
3	135	239.52	45.61	0.290	187,760	0.514	$0.232 \leq p_3 \leq 0.348$*
4	23	31.69	2.38	0.049	24,791	0.068	$0.022 \leq p_4 \leq 0.076$
Total	466	466	1,423.60		365,409		

* = significance ascribed if the confidence interval does not include the percentage of the total area of the respective cell

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Water *Velocity* Use. - Water velocities 1 m below the surface at 59 squawfish positions within the tailrace of Lower Granite Dam ranged from 0 to 1.7 m/s and averaged 0.27 m/s, with eighty-five percent of the squawfish in water velocities < 0.6m/s. Water velocities at 38 random positions had a mean of 0.58 m/s and ranged between 0 and 1.6 m/s. Water velocities at the locations of squawfish with transmitter differed significantly from velocities at random positions in the tailrace (G_H = 9.44, p < 0.005).

Squawfish activity *pattern.* - Twenty-nine different squawfish with transmitters were tracked for 155 hours and relocated a total of 784 times during seven continual tracking periods in the tailrace of Lower Granite Dam in 1993. Mean movement rates of squawfish differed significantly by time of day (F = 1.99, p = 0.0276; Figure 16). Fourteen of the 61 pair-wise comparisons conducted on the transformed savage scores were significantly different (P $\leq$ 0.05). Movement rates were in a mid range during daylight hours (51.20 - 60.46 m/h), and higher during morning and evening crepuscular periods (86.79 and 98.89 m/h). Movement rates dropped to their lowest levels (29.11 and 41.01 m/h) after each crepuscular peak.

Forty-eight different squawfish with transmitters were recorded in 721 hourly observations at the receiver on the juvenile collection facility barge dock during 1992 and 1993. The resulting hourly distribution of squawfish recorded near the dock was not uniform (U^2 = 4.668, p< 0.01; Figure 17), but skewed towards crepuscular and night hours. Based on a sign test, we concluded that significantly more squawfish observations occurred near the upstream end of the barge dock (p = 0.002), a result that agrees with the distribution of squawfish observed during the postspill period (Figure 12).

Day period (245 observations; June 9 to August 20)

N

1

2

3

4

Night period (221 observations; June 12 to August 20)

1

2

3

4

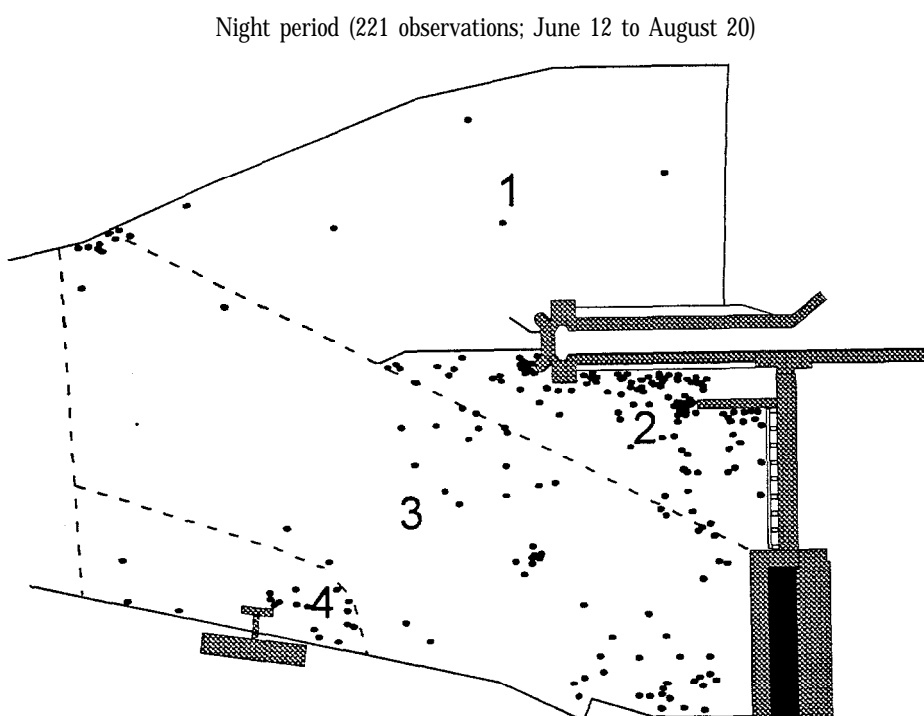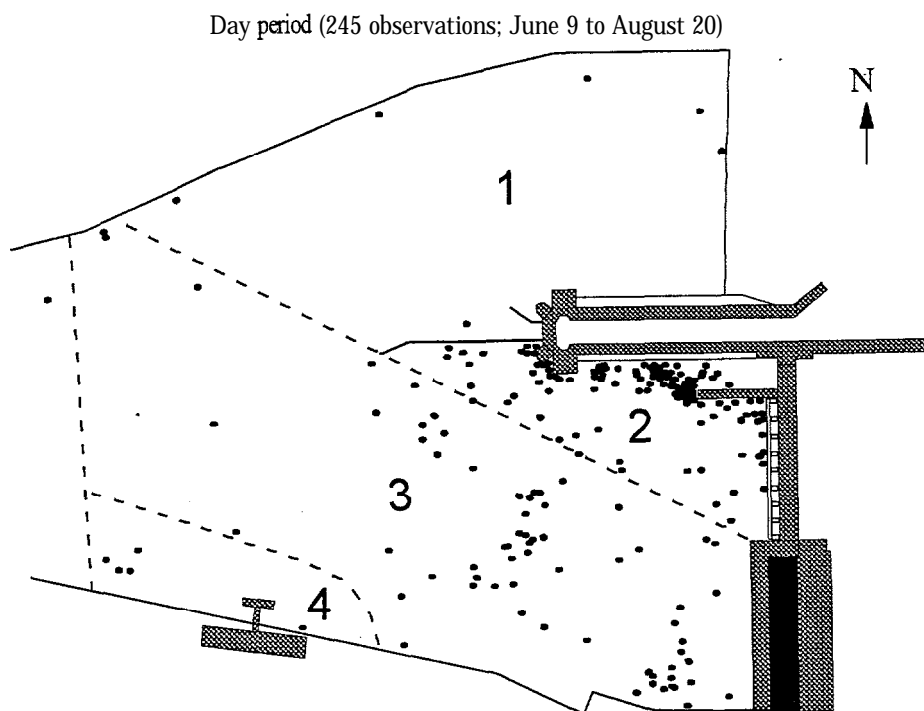Figure 14. Distributions of squawfish in the tailrace of Lower Granite Dam during two diel periods after the completion of spill in 1993.
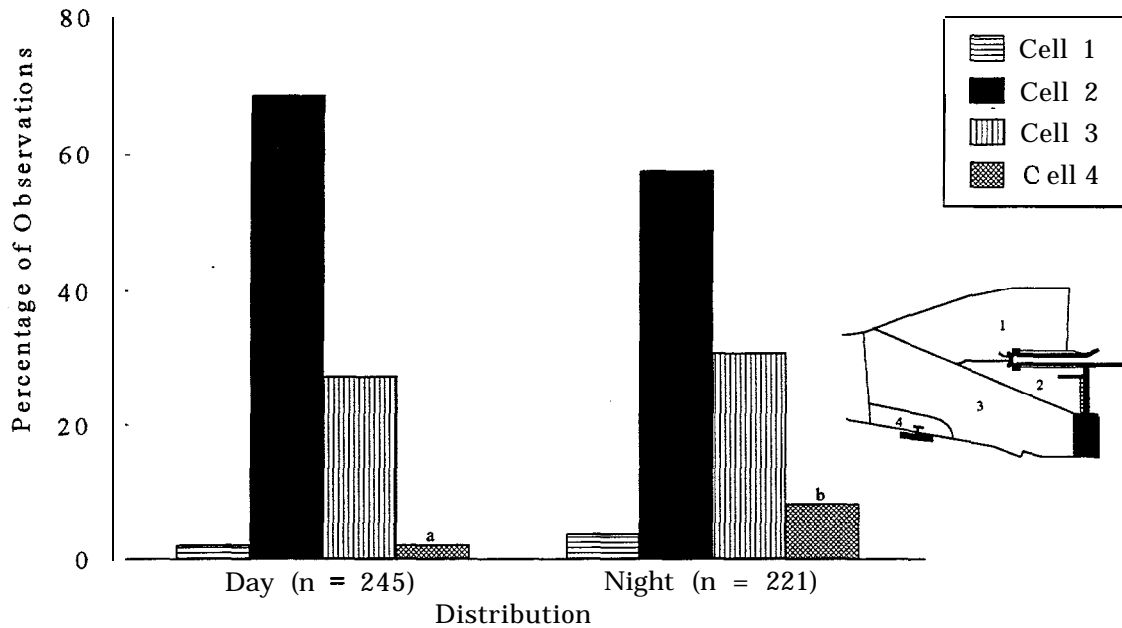
Figure 15. Comparison between day and night distributions of squawfish in the tailrace of Lower Granite Dam after the completion of spill in 1993. Bars with letters differ significantly from their counterpart (P < 0.05). Overall distributions are significantly different (P < 0.05).

Table 4. Use-availability analysis of squawfish observations within the tailrace of Lower Granite Dam during two diel periods in 1993.

Cell	Observed	Expected	χ^2	Percent of observations	Area (m^2)	Percent of total area	Bonferroni confidence interval
				Day			
1	5	76.93	67.25	0.020	114,782	0.314	$0 \leq p_1 \ 50.045$"
2	168	25.48	797.17	0.686	38,074	0.104	$0.605 \leq p_2 \leq 0.767$*
3	67	125.93	27.58	0.273	187,760	0.514	$0.195 \leq p_3 \leq 0.351$*
4	5	1.666	8.16	0.020	24,791	0.068	$0 \leq p_4 \leq 0.045$*
Total	245	245	900.16		365,409		
				Night			
1	8	69.39	54.31	0.036	114,782	0.314	$0.002 \leq p_1 \leq 0.070$*
2	127	22.98	470.85	0.575	38,074	0.104	$0.484 \leq p_2 \leq 0.666$*
3	68	113.59	18.30	0.308	187,760	0.514	$0.223 \leq p_3 \leq 0.393$*
4	18	15.03	0.59	0.081	24,791	0.068	$0.031 \leq p_4 \leq 0.131$
Total	221	221	544.05		365,409		

* = significance ascribed if the confidence interval does not include the percentage of the total area of the respective cell

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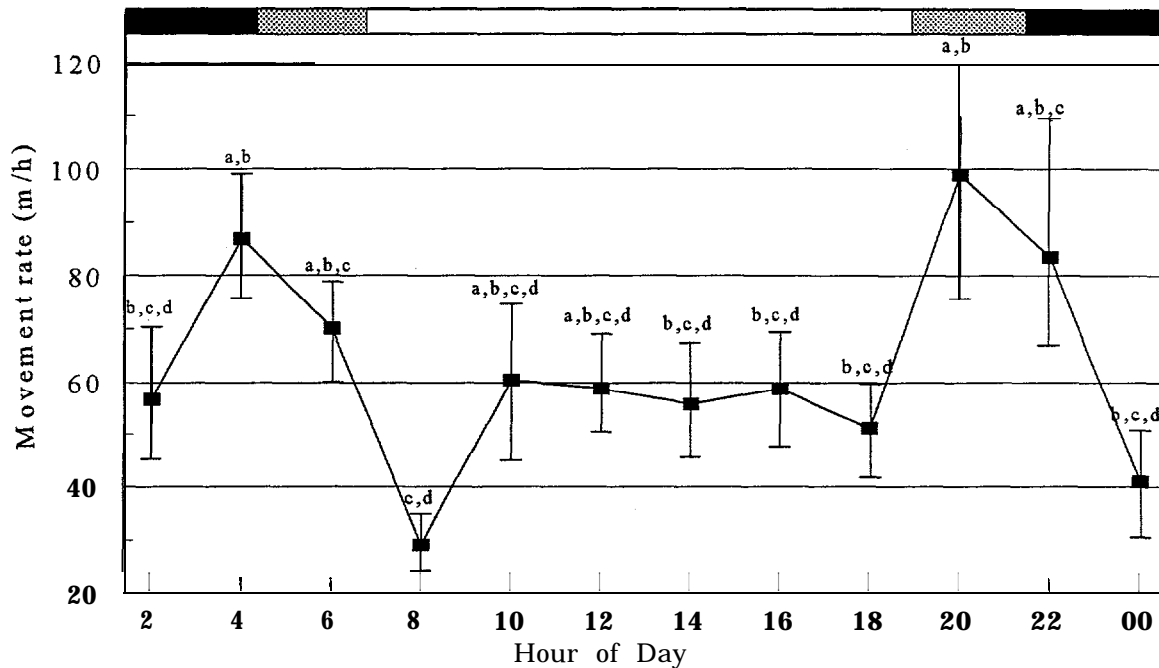
Figure 16. Movement rates of squawfish during two hour periods in the tailrace of Lower Granite Dam between June 3 and August 5, 1993. Shading denotes diurnal (white), nocturnal (black), and crepuscular (grey) periods. Vertical bars represent $\pm$ 1 SE, time periods without letters in common are significantly different (P $\leq$ 0.05).
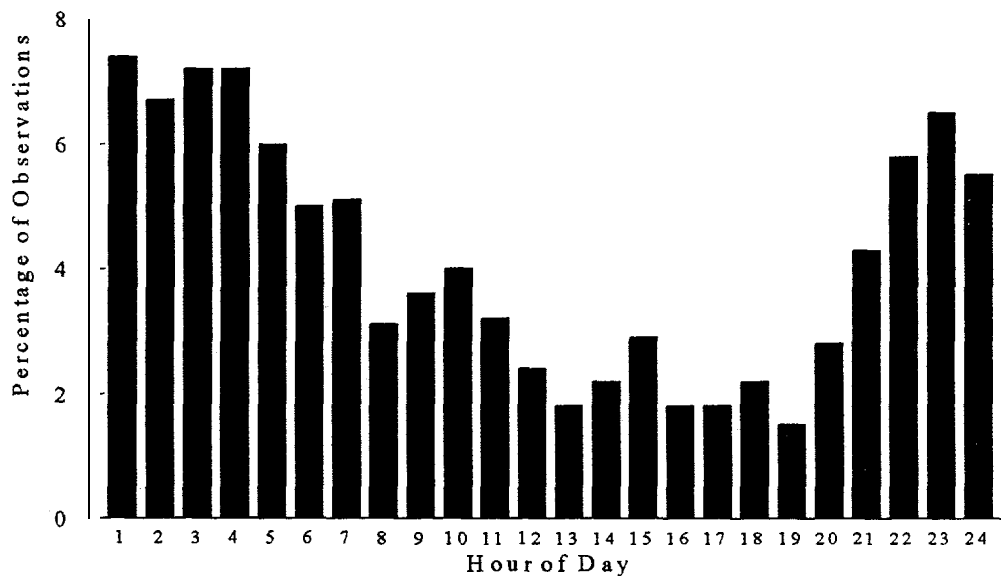
Figure 17. Percentage of squawfish observations (n = 721) near the juvenile collection facility in the tailrace of Lower Granite Dam during 1992 and 1993 that were recorded each hour of the day. Distribution differs significantly from uniform (P < 0.01).

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Squawfish Home Ranges. - Home range estimates were calculated within the Lower Granite Dam tailrace for five squawfish with twenty-five or more observations during the postspill period (Figures 18, 19, 20, 21, and 22), and the distributions of observations for fish with sample sizes less than 25 are summarized in Appendix C. Home range estimates (area circumscribed by the 90% contour) ranged from 7,822 to 188,163 m^2, with a mean of 70,185 m2 (Table 5). Home range size, shape, and location varied considerably, but reflected use of the stilling basin (cell 2) and multiple centers of activity by the squawfish.

**Distribution in Reservoir.** - Forty-three different squawfish with transmitters were observed 152 times in Little Goose Reservoir during five surveys from June 26 to November 20, 1993. The distribution of squawfish differed significantly over this period (GH = 33.00, p < 0.01; Figure 23). During the first three surveys, 82 - 90% of the squawfish located were in the tailrace or upper third of the reservoir, but by the September 18 and November 20 surveys, a higher proportion of squawfish with transmitters were located in the lower two-thirds of the reservoir. During the first four surveys, at least 39% of squawfish observations were in the tailrace of Lower Granite Dam, but this proportion decreased to 5% by November 20.

Figure 18. Home range of squawfish 29-02 in the tailrace of Lower Granite Dam during the postspill period of 1993. Numbers denote the percentage contours of the home range.

Figure 19. Home range of squawfish 30-68 in the tailrace of Lower Granite Dam during the postspill period of 1993. Numbers denote the percentage contours of the home range.
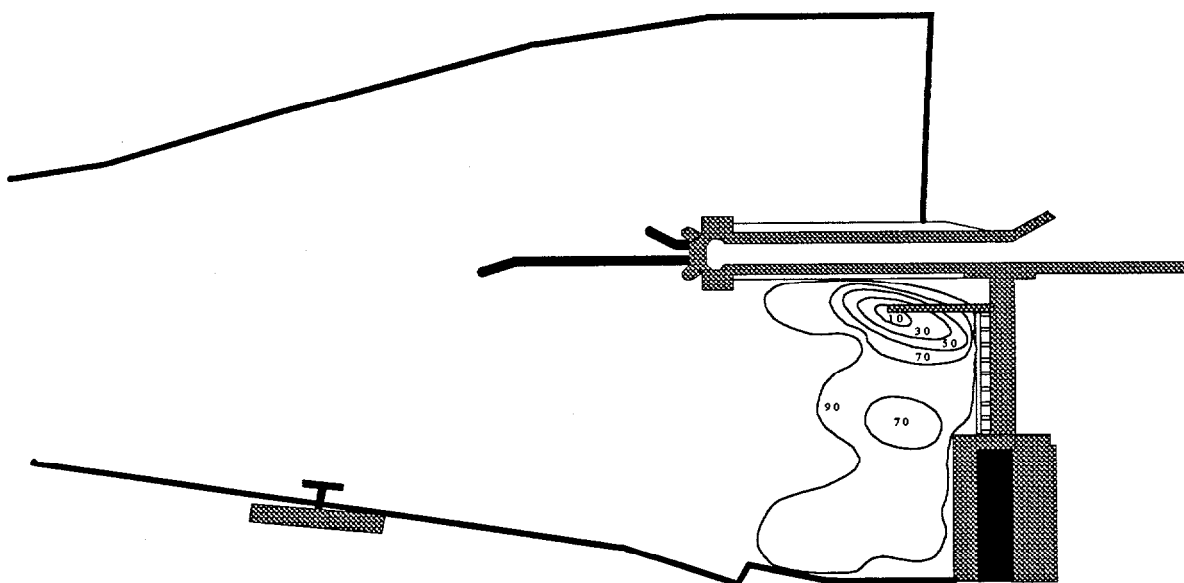
Figure 20. Home range of squawfish 32-76 in the tailrace of Lower Granite Dam during the postspill period of 1993. Numbers denote the percentage contours of the home range.
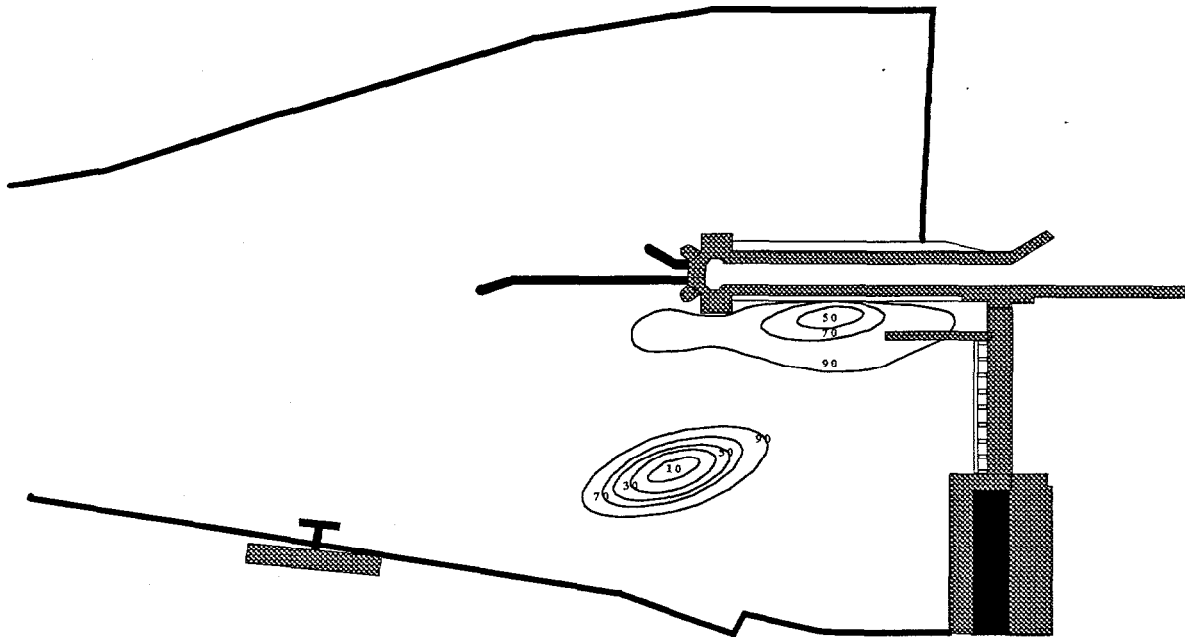
Figure 21. Home range of squawfish 31-74 in the tailrace of Lower Granite Dam during the postspill period of 1993. Numbers denote the percentage contours of the home range.
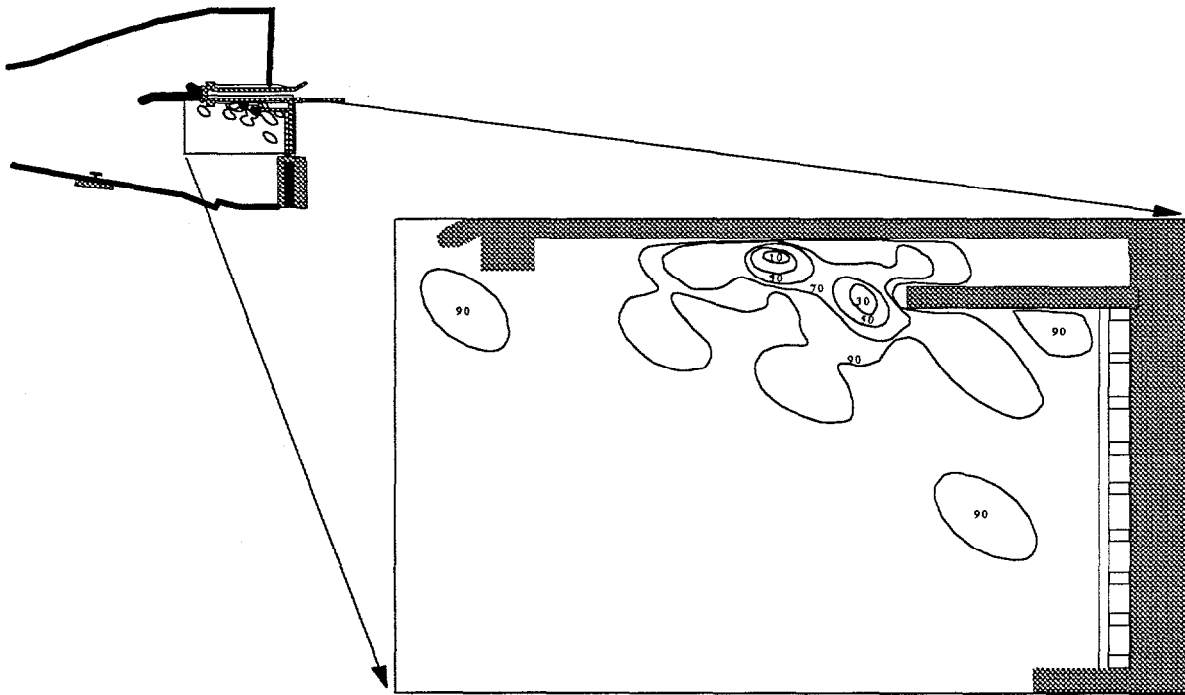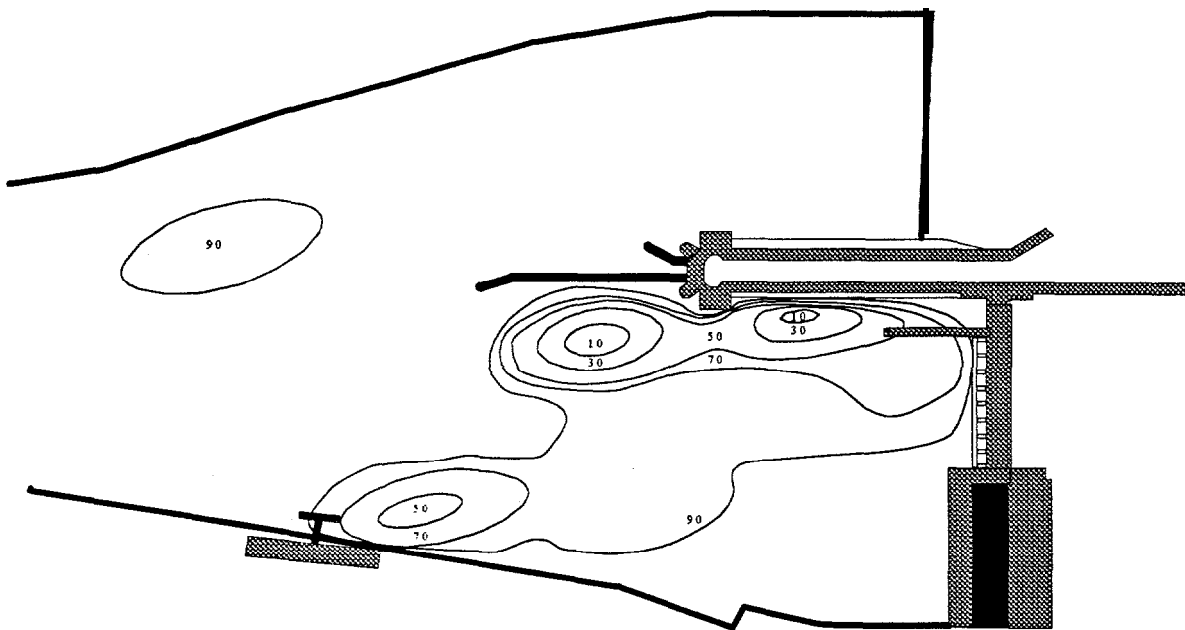

Figure 22. Home range of squawfish 31-72 in the tailrace of Lower Granite Dam during the postspill period of 1993. Numbers denote the percentage contours of the home range.
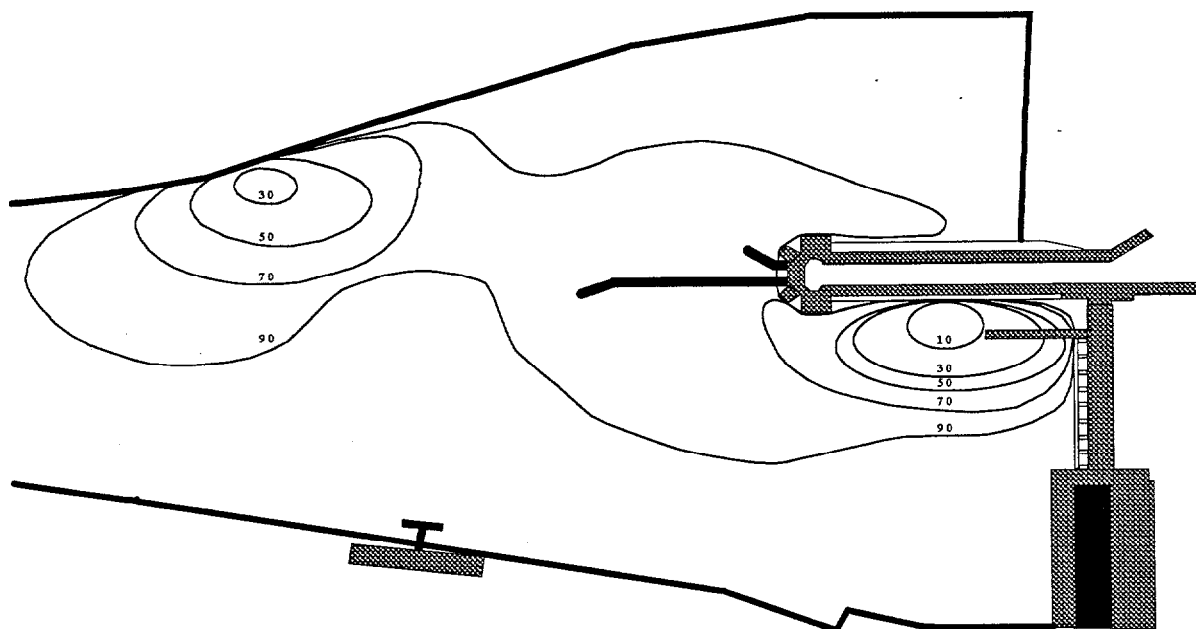
Table 5. Areas (m2) circumscribed by percentage contours of squawfish home ranges in the tailrace of Lower Granite Dam during the postspill period of 1993.

Fish code	Percentage contour				
	10%	30%	50%	70%	90%
29-02	67	291	670	1,944	7,822
30-68	3,704	14,075	28,150	57,042	188,163
32-76	548	2,082	4,273	10,627	35,167
31-74	585	2,106	4,681	8,309	21,065
31-72	2,357	9,134	21,509	45,375	98,706
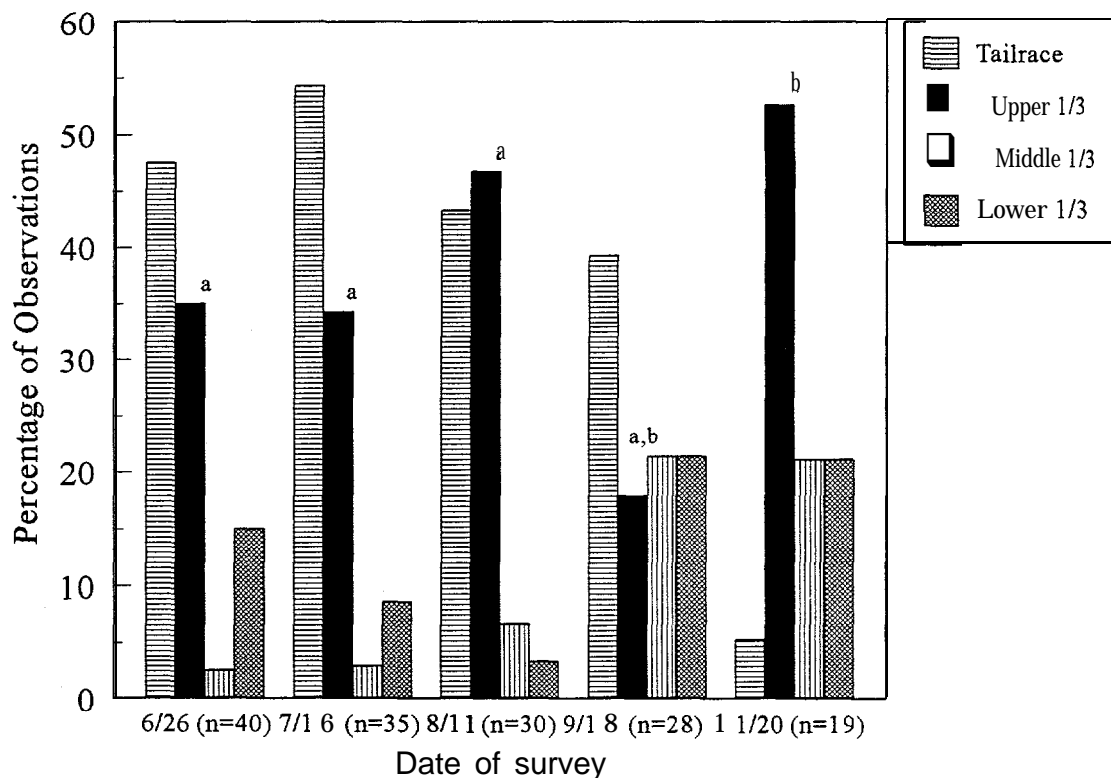
Figure 23. Comparisons between distributions of squawfish throughout Little Goose Reservoir from June 26 to November 20, 1993. Distributions without letters in common are significantly different (P < 0.01).

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Discussion

***Squawfish abundance and distribution.* -** The abundance of squawfish-with transmitters in the tailrace of Lower Granite Dam appeared to be inversely related to river discharge in 1993, a finding consistent with a study by Bentley and Dawley (1981) that detected downstream movements of squawfish in the lower Snake River during periods of high discharge. This is not surprising given the swimming ability of squawfish; Mesa and Olson (1993) found that adult squawfish forced to swim in 12°C water at 1 m/s fatigued in approximately 20 minutes. If these experimental results are transferable to a natural setting, most of the tailrace and a section of the reservoir immediately downstream could not be occuppied for extended periods by squawfish during much of the spring when water velocities consistently exceeded 1 m/s and were often faster than 2 m/s.

Abundance of squawfish with transmitters in the Lower Granite Dam tailrace during 1993 was highest in early May (28% of tagged fish) before peak discharge and again after peak discharge (39% of tagged fish). Beamesderfer and Rieman (1991) speculated that squawfish exhibited a numerical response to high juvenile salmonid numbers in the tailrace of McNary dam, where squawfish abundance was 12 - 18 times higher than in the remainder of John Day Reservoir. The early peak we observed may have been a similar response that became truncated as increasing flows exceeded the swimming ability of squawfish. A second peak in squawfish abundance occurred after flows subsided. The second peak was probably related to squawfish spawning activity. Bennett et al. (1983) has documented squawfish spawning at this time in the lower Snake River and other researchers have documented movements of squawfish and their congenerics as spawning approached (Casey 1962; Reid 1971; Tyus 1990).

Many things in nature are patchily distributed (Elton 1949; Reice 1974). We assumed this was the case in the tailrace of Lower Granite Dam where juvenile salmonid densities were likely highest in areas of flowing water downstream from the powerhouse and spill gates (when spill occurred) and lowest in standing water north and immediately south of the navigational lock (cells 1 and 2). Squawfish were rarely found in areas of high velocity and presumably highest prey density. Instead, they were found most often in low velocity habitats, a finding consistent with that of others (Beamesdetfer 1983; Faler et al. 1988). Prey densities may have been high enough throughout the tailrace so that squawfish were not required to enter higher velocity areas to encounter prey. Alternatively, Petersen and DeAngelis (1992) provided evidence that squawfish feed infrequently and during brief periods. If this is the case in the Lower Granite Dam tailrace, squawfish movements into high velocity areas and high prey densities could then be brief and this would help explain the low proportion of observations in flowing water. Finally, we believe the diel chronology of squawfish activity (to be discussed later) suggests that foraging intensity may have been greatest during crepuscular periods. Early morning and evening periods were not routinely sampled, and a larger proportion of squawfish observations may have occurred in areas with higher densities of prey at those times.

Water temperature and prey density may also have affected the tailrace distribution of squawfish. Flow patterns were similar during early and late periods in 1992 and prespill and postspill periods in 1993, yet the distribution- of squawfish within each year differed significantly. Relatively large numbers juveniles migrated during the early period in 1992 and prespill period in 1993. Twenty-four percent of squawfish with transmitters in 1992 and 41% in 1993 were observed in the slackwater north of the lock (cell I), away from the areas with highest prey densities. During the late period in 1992 and the postspill period in 1993, the downstream migration of salmonids had decreased significantly, yet most squawfish moved to the slackwater south of the lock (cell 2) and few (2% in 1992, 3% in 1993) were then observed north of the lock. We speculate that these distributional shifts were related to decreasing prey abundance and increasing water temperatures (early period mean in 1992 = $13.3°$ C, late period mean = $18.8°$ C, prespill period mean in 1993 = 10.0" C, postspill period mean = $16.7°$ C) and the effect that they had on squawfish foraging activity and metabolic rates. Several studies have documented increasing consumption rates and gastric tract evacuation of squawfish as temperatures increase (Falter 1969; Beyer et al. 1988; Vigg and Burley 1991). Vigg et al. (1991) estimated that squawfish in the tailrace of McNary Dam had a mean total daily ration of 6 mg/g at $9°$ C and 30.3 mg/g at $19°$ C. Squawfish likely required smaller daily rations during the prespill and early periods and probably did not have to forage actively. However, during later periods in both years, temperatures were higher, metabolic demands greater, and prey densities lower. Squawfish may have moved to the slackwater south of the lock because it provided improved foraging opportunities near the discharge from the powerhouse.

River conditions may help explain annual differences in tailrace distributions of squawfish. Water temperatures were warmer in 1992 than in 1993, and metabolic demands probably forced squawfish to begin actively foraging earlier in 1992. Additionally, no spill occurred at Lower Granite Dam in 1992 because of low river discharge, and squawfish were not excluded from large portions of the tailrace by high water velocities. As a result, the distribution of squawfish in 1992 showed a larger degree of overlap with juvenile salmonids during peak migration times. The late implantation of transmitters in fish, their release location, and poor transmitter performance made it impossible to monitor squawfish abundance in the tailrace in 1992, but river conditions were conducive to an increase in abundance earlier in the year.

Because predation and factors that control it are dynamic, losses to predation for each species of juvenile salmonid differs. Steelhead trout, spring and summer chinook salmon, and sockeye salmon smolts migrate through the lower Snake River in April, May, and early June, when water temperatures are cool and river discharge is increasing or peaking. These early migrants move through tailrace areas at times when predator abundances are low, consumption rates are low, and distributional overlap may be minimal. Fall chinook salmon smolts, on the other hand, migrate later in the summer when predator consumption rates and abundances have increased and distributional overlap is greater. Additionally, subyearling fall chinook salmon are

may be minimal. Fall chinook salmon smolts, on the other hand, migrate later in the summer when predator consumption rates and abundances have increased and distributional overlap is greater. Additionally, subyearling fall chinook salmon are diverted into bypass and collection systems at lower rates than the other juvenile migrants (Krcma et al. 1986) and a larger proportion of fall chinook salmon migrants pass through the tailrace and are subject to predation. For these reasons, we believe the fall chinook salmon migrants are more affected by squawfish predation in tailrace areas than the other juvenile migrants.

Squawfish activity pattern. - Diel activity patterns are common in fish and are often driven by endogenous circadian rhythms (Thorpe 1978), cyclical changes in environmental conditions, or changes in prey densities (Helfman 1993). Movement rates of squawfish in the tailrace of Lower Granite Dam appeared to peak during morning and evening crepuscular periods. We assumed that increased movement by squawfish was indicative of increased foraging activity and resulted in more prey encounters. Uremovich et al. (1980) reported that squawfish fed most actively in the forebay of Bonneville Dam during crepuscular periods, and it is common for predators to forage under low light conditions when the reactive distance of prey is decreased (Cerri 1983; Howick and O'Brien 1983). However, the feeding chronology of squawfish in the tailrace of McNary Dam differed from the activity we observed at Lower Granite Dam. Peak feeding in the McNary tailrace occurred from 0600 to 1000 and 0000 to 0400 (Vigg et al. 1991). Several studies suggest that juvenile passage chronologies vary between hydroelectric projects with the majority of smolts passing during low-light hours being the only constant (Park et al. 1976; Sims et al. 1976; Gessel et al. 1986; Johnsen et al. 1986). Foraging habits of fishes have been characterized as being adaptively flexible (Dill 1983) and squawfish may be altering their foraging strategy at different dams to take advantage of times when prey are most vulnerable.

Bypass outfall location. - The area near the juvenile collection facility was of special interest because juvenile salmonids are concentrated when fish are returned to the river and increased predation may result. Ledgerwood et al. (1994) documented decreased survival of juvenile salmonids passing through the bypass system at Bonneville Dam and predation was thought to be the cause. At no time in either year were large numbers of squawfish observed near the bypass outfall at Lower Granite Dam, but sampling underestimated the number of observations in this area because fishermen removed several squawfish with transmitters from the immediate vicinity of the juvenile bypass. Squawfish probably did not congregate near the juvenile bypass outfall because it was in an area of flowing water devoid of low-velocity refuges, and the bypass was used infrequently to return juveniles to the river in 1992 and 1993. Sporadic use of the bypass to return fish to the river may have prevented squawfish from associating the area with profitable foraging.

Most observations of squawfish near the juvenile bypass in 1993 occurred at night and were taken on 6 individuals located on multiple occasions. Fish that moved into the bypass outfall area were typically found slightly upstream from the barge dock

before it is discharged (Tim Wik, USACOE, personal communication). The distribution of squawfish in the bypass area was not an immediate predation threat because most were located upstream from the bypass outfall, but it is an indication that squawfish are capable of adapting to things which are predictable in nature. If the bypass outfall were used regularly to return juvenile salmonids to the river, aggregations of squawfish could develop.

Individual variafion. - Studies of organisms are often scaled to look at population averages, a practice that obscures behavioral differences of individuals. It also creates the illusion of an average organism, when, in fact, no such creature exists. Partridge and Green (1985) suggested that individual variability results from a variable environment, phenotypic differences, and the behavior of other individuals. Therefore, the variation observed between individuals or within an individual represents different strategies for satisfying the needs of that individual.

A wide range of differences in individual behavior was documented during the course of this study. Home range estimates of squawfish varied considerably, with some restricted to small areas while others encompassed most of the tailrace. Differences in home range size and shape may have resulted from variable foraging efficiencies, different metabolic demands, or the interaction of the sampling regime (midday and midnight) with individual differences in diel activity patterns. Variability between individuals was illustrated by squawfish 34-66 (Appendix B, Figure 32) and 34-64 (Appendix B, Figure 36) that were located approximately 20 times during the same 24-hour period on August 5, 1993. Squawfish 34-66 moved little and split its time between two areas near the navigational lock, while fish 34-64 moved extensively during this time period, even leaving the tailrace for a few hours near sunrise. These fish were subject to identical environmental conditions, but exhibited different amounts of movement on a single day. Variability also occurred within individuals. Evidence of this was provided by squawfish 28-76. This fish was monitored during roughly the same time period on July 8 and August 5, 1993 (Appendix B, Figures 20 and 39). The fish moved continuously about the tailrace on July 8, never staying in one position for long. The next month, it occupied a position near the lock during the entire tracking period.

Distribution in reservoir. - Fish distributions and habitat selection change seasonally in response to food availability, temperature, photoperiod, and other factors which can influence scope of activity, survival, and growth (Hall and Werner 1977; Grossman and Freeman 1987; Baltz et al. 1991). The distribution of squawfish with transmitters in Little Goose Reservoir was relatively constant through summer, with the majority of the fish located in the upper one-third of the reservoir and the tailrace; however, this may be an artifact of their release location, and conclusions regarding spawning or predation related activities are not warranted, based on this data. During September, a larger proportion of squawfish was observed in the lower two-thirds of the reservoir and most had left the tailrace and moved into the reservoir by the November survey. Bennett et al. (1983)

observed similar downstream movement of squawfish in Little Goose Reservoir and Olney (1975) noted movement of squawfish into deeper water in Lake Washington as fall approached. Movement into deeper water for overwintering purposes is common among fish (Langhurst and Schoenike 1990; Baltz et al. 1991) and squawfish may have left the tailrace and moved down into Little Goose Reservoir because deepwater ovetvvintering areas are more common in the reservoir.

Reservoir surveys were biased because radiotelemetry signals were adversely affected by increasing water depth, and deepwater habitats are more common in the downstream end of the reservoir. This bias may have resulted in underestimation of squawfish abundance in the deeper parts of the reservoir, but comparability between reservoir surveys was not affected if depth selection by squawfish remained constant throughout the year. If squawfish selected deeper water later in the year, the bias was not constant, and we increasingly underestimated the number of squawfish in the lower reservoir leading to conservative results.

ICE HARBOR DAM STUDY

Study Area

Ice Harbor Dam, at river kilometer 14.5, was the first of four dams constructed in the lower Snake River. Ice Harbor Dam was chosen as a study site because it was the only lower Snake River project without a juvenile collection facility, but a bypass and collection facility was scheduled for construction in 1995-1996 and information regarding the distribution of predators in the tailrace will prove useful when siting the bypass outfall.

The navigation lock lies along the north shore at Ice Harbor Dam, the spillway is in mid-channel, and the powerhouse extends from the south shore (Figure 24). The powerhouse at Ice Harbor Dam has a capacity of 2,940 m^3/s, and excess is spilled through up to 10 tainter gates (USACOE, unpublished). Water velocities within the tailrace range from near zero to 5.0 m/s (Figure 25), and water from the navigation lock is discharged at random intervals near the southwest corner of the lock.

Migrating juvenile salmonids pass Ice Harbor Dam via the spill, through the powerhouse, or in the ice and trash sluiceway (Figure 24). Because no collection facility yet exists, juveniles diverted by submersible traveling screens from turbine intakes are returned to the tailrace through the ice and trash sluiceway. Species composition and migration timing of the juvenile salmonids at Ice Harbor Dam is similar to that at Lower Granite Dam. Relative abundance of the different species are also similar although fall chinook salmon make up a larger portion of the migration due to releases at Lyons Ferry Hatchery.

Continuous spill occurred at Ice Harbor Dam from early May until late June of 1993 (the only year of study at Ice Harbor Dam). Continuous spill duration was

longer at Ice Harbor Dam because of smaller powerhouse capacity and some turbines that were inoperable. Irregardless of river discharge, water was spilled at night to aid juvenile passage of the dam.
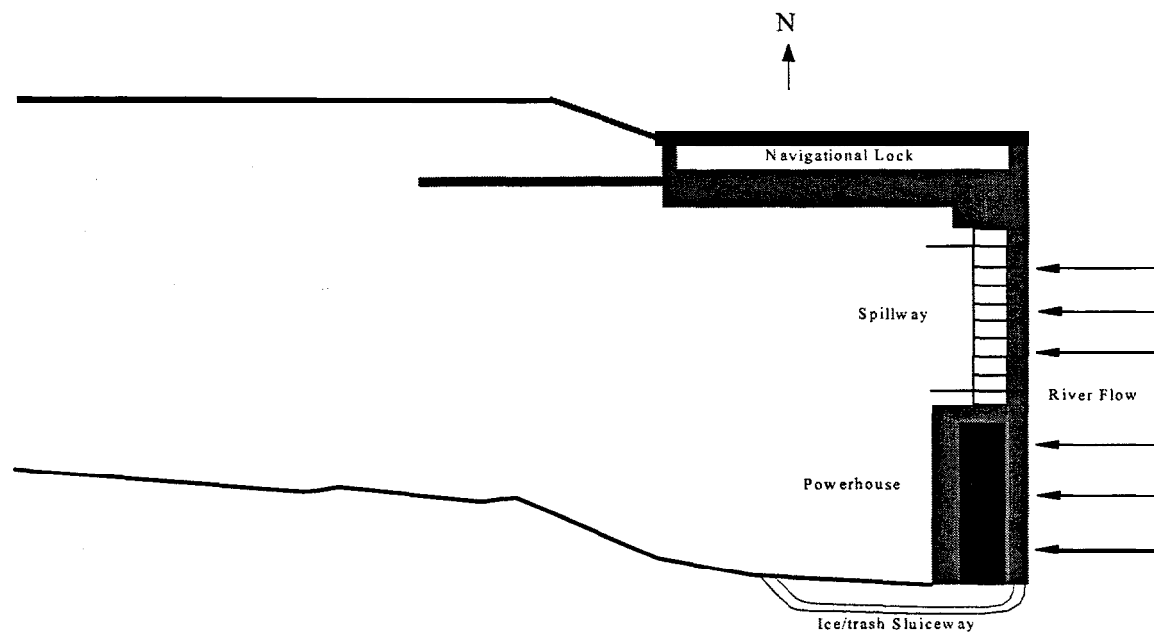
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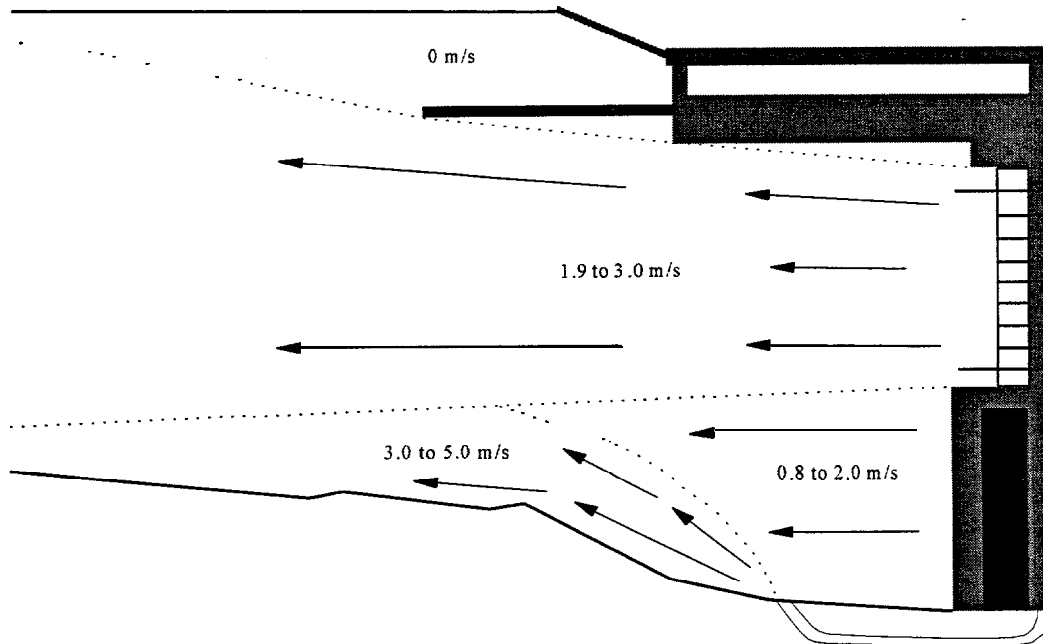Figure 24. Tailrace of Ice Harbor Dam on the lower Snake River in southeast Washington.

The Snake River downstream of Ice Harbor Dam runs for 14.5 km to its confluence with the Columbia River. Much of this river section is shallow (< 3 m) with the exception of a barge channel which is dredged to a depth of 7 m. The Snake River downstream from Ice Harbor Dam has a mean elevation of 102 m and widths range from 115 m to 275 m.

Methods

Collection and transmitter implantation procedures for squawfish were similar to those used at Lower Granite Dam. Collection and implantation of squawfish at Ice Harbor Dam began on May 12 of 1993. Similar to Lower Granite Dam, catch rates were low and most fish were collected downstream of the tailrace. The collected fish were taken to a central location 2 km downstream of Ice Harbor Dam, implanted with transmitters, and released after recovery. Seventeen squawfish with transmitters were released downstream of Ice Harbor Dam in 1993 (Appendix A).

Data collection techniques. - Squawfish with transmitters were relocated downstream of Ice Harbor Dam by homing on their positions with a boat and at a

Flow pattern during spill at Ice Harbor Dam.
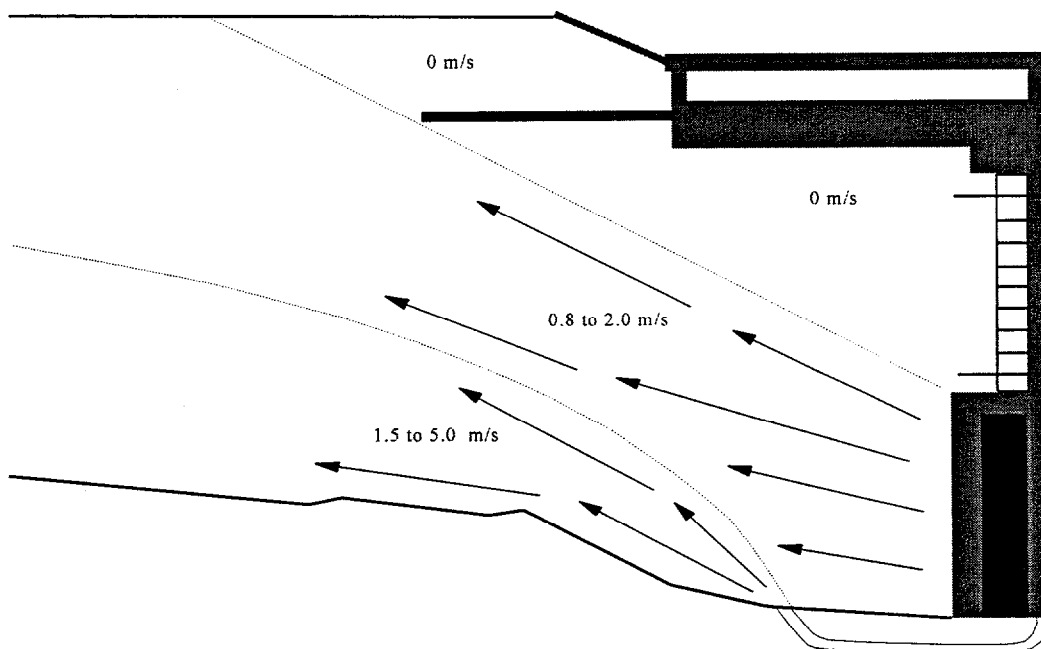

Flow pattern during no spill at Ice Harbor Dam.

Figure 25. Flow patterns and velocities within the **tailrace** of Ice Harbor Dam during spill and no spill conditions in 1993.

fixed receiver site. Equipment configuration and homing procedures used to locate fish with the boat were identical to those used at Lower Granite Dam. The fixed location receiver was linked to a six-element antenna and monitored an area adjacent to the ice and trash sluiceway outfall.

Squawfish distribution. - Squawfish in the tailrace of Ice Harbor Dam were located by boat approximately every 10 days beginning in late May of 1993 (Table 6). All observations were made during daylight hours and were stratified into continuous or night only spill periods.

Squawfish Activity Pattern. - Data from the fixed location receiver was used to estimate chronology of squawfish activity near the ice and trash sluiceway outfall. The receiver continuously monitored this area from June 7 to August 17 (Table 6). Activity chronology was estimated by allowing one observation per fish per hour to avoid biasing the sample towards those fish which lingered within the range of the antenna. The hourly distribution of these observations was tested for uniformity using a Watson edf test (Stephens 1974).

Disfribufion Downstream of Dam. - Squawfish between Ice Harbor Dam and the mouth of the Snake River were located with the boat approximately every ten days beginning in late May (Table 6). Data collection techniques were identical to those employed in Little Goose Reservoir.

Table 6. Sampling schedule for squawfish with transmitters downstream of Ice Harbor Dam durina 1993.

	Week	Tailrace distribution	Fixed receiver	Downstream distribution
May	1			
	2			
	3			
	4	X		X
June	1	X	X	X
	2		X	
	3	X	X	X
	4	X	X	X
July	1		X	
	2	X	X	X
	3	X	X	X
	4		X	
August	1	X	X	X
	2		X	
	3	X	X	X

Results

Squawfish Distribution. – Few transmitter-equipped squawfish moved upstream into the tailrace of ice Harbor Dam during 1993. During the continual spill period, squawfish were usually found in slackwater north of the lock guidewall (Figure 26). After night-only spill began at Ice Harbor Dam, most fish were found during the day in the slackwater of the spill basin.

Squawfish activity pattern. – Four hundred seventy-six hourly observations from 6 different squawfish were recorded on the receiver located near the sluiceway outfall in the tailrace of Ice Harbor Dam. The diel distribution of observations differed significantly from uniform (U2 = 4.594, $p < 0.01$; Figure 27) and was similar to the trend observed at Lower Granite Dam, with most observations at night or during crepuscular hours.

Distribution Downstream of Dam. – The stretch of river between Ice Harbor Dam and the mouth of the Snake River was searched for squawfish with transmitter nine times between May 25 and August 17. Most squawfish were found either in the tailrace or midway between the dam and the Columbia River confluence through mid June (Figure 28). After this, a few squawfish were still found in the tailrace, but most fish apparently moved from the study reach. Several squawfish were subsequently located in the Columbia River near the mouth of the Snake River.

Discussion

Squawfish Distribution. – Few of the squawfish with transmitters moved into the tailrace of Ice Harbor Dam during 1993. Abundance was highest on June 30 and July 11 when four fish were found in the tailrace. Because of a longer spill duration, shallower tailrace depth, and a high velocity discharge from the ice and trash sluiceway, high water velocities occurred for a longer period of time and were of greater magnitude in the tailrace of Ice Harbor Dam than those observed in the Lower Granite Dam tailrace. Given the swimming ability of squawfish (Mesa 1994) and the inverse relationship between river discharge and squawfish abundance in the tailrace of Lower Granite Dam, we believe water velocity limited the number of squawfish in the taiirace of Ice Harbor Dam during 1993.

Similar to the pattern observed at Lower Granite Dam, the distribution of squawfish in the Ice Harbor Dam tailrace was related to flow velocities in various areas. During continual spill, most squawfish were located in slackwater north of the lock guidewall. When no spill occurred during the day, squawfish were usually found in the slackwater of the spill basin. No samples were taken at night, so it is unknown if squawfish moved back to the low velocity refuge created by the lock guidewall when spill began in the evening.

Continual spill locations (7 observations; May 25 to June 17)
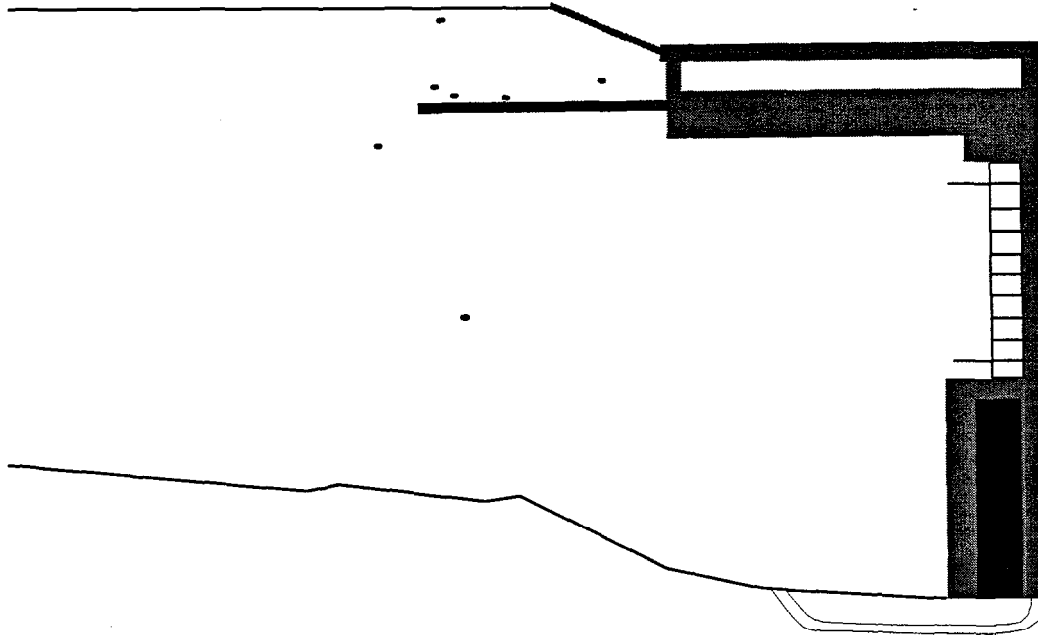
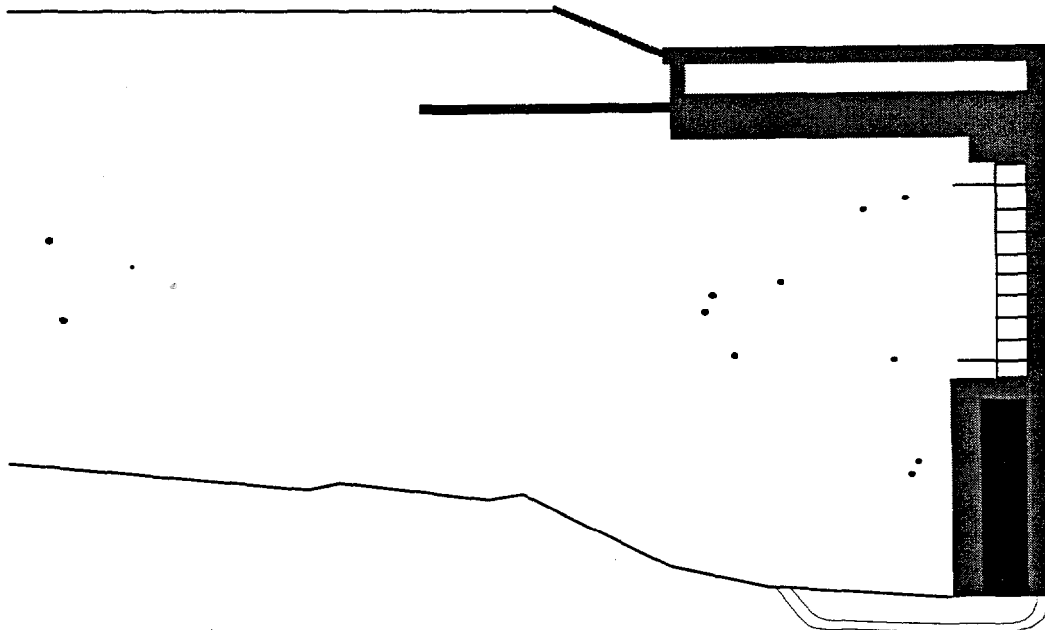Night spill only locations (13 observations; June 30 to August 17)

Figure 26. Distributions of squawfish in the tailrace of Ice Harbor Dam during continual spill and night only spill in 1993.
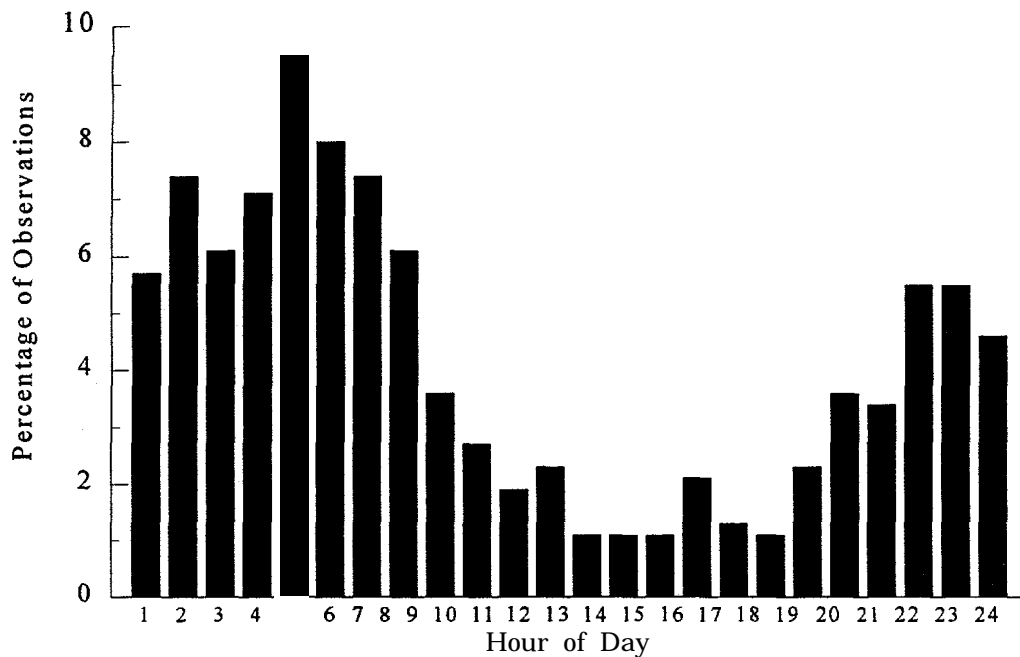
Figure 27. Percentage of squawfish observations (n = 476) near the ice and trash sluiceway outfall in the tailrace of Ice Harbor Dam during 1993 that were recorded each hour of the day. Distribution differs significantly from uniform (P < 0.01).

At no time were squawfish observed near the ice and trash sluiceway outfall. High water velocity in this area may have prevented squawfish from maintaining postions in this area, but this conclusion should be viewed carefully because no night sampling occurred at Ice Harbor Dam and sampling efficiency in this area was limited due to shallow water depth, high water velocities, and significant amounts of electrical interference.

Squawfish activity pattern. - The chronology of squawfish activity near the ice and trash sluiceway outfall was similar to that observed near the bypass outfall in the tailrace of Lower Granite Dam. Most observations occurred during night or crepuscular hours. However, the interpretation of these results must be exercised with caution because of the small number of fish represented in the sample (n = 6) and the impossibility of quantifying the reception range of the antenna due to the turbulent waters near the ice and trash sluiceway outfall. Additionally, the reception range of the antenna may have been altered by periodic changes in electrical interference.

Distribution Downstream of Dam. - It is difficult to explain the distribution of squawfish downstream from Ice Harbor Dam in 1993. Most squawfish were
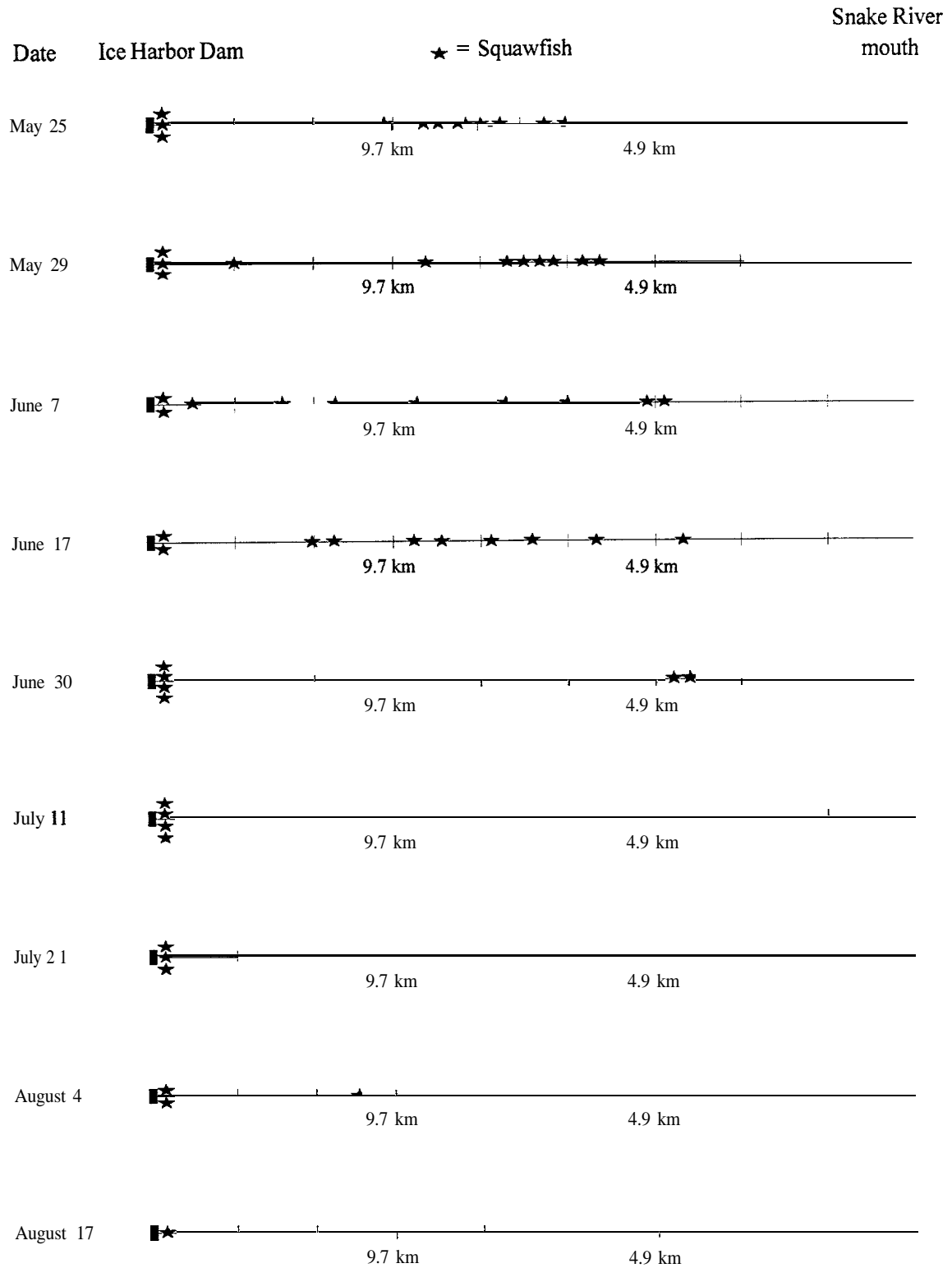
Figure 28. Distributions of squawfish with transmitters between Ice Harbor Dam and the mouth of the Snake River in 1993.

found midway between the dam and the mouth of the Snake River during the early part of the summer, but many of the fish left the Snake River and most apparently moved to the Columbia River (three fish found within 5 km of Snake River mouth) about the time that spawning has been documented in the lower Snake River (Bennett et al. 1983). It is unknown whether squawfish left the Snake after completion of spawning, because high velocities kept them from preferred spawning locales, or for other reasons.

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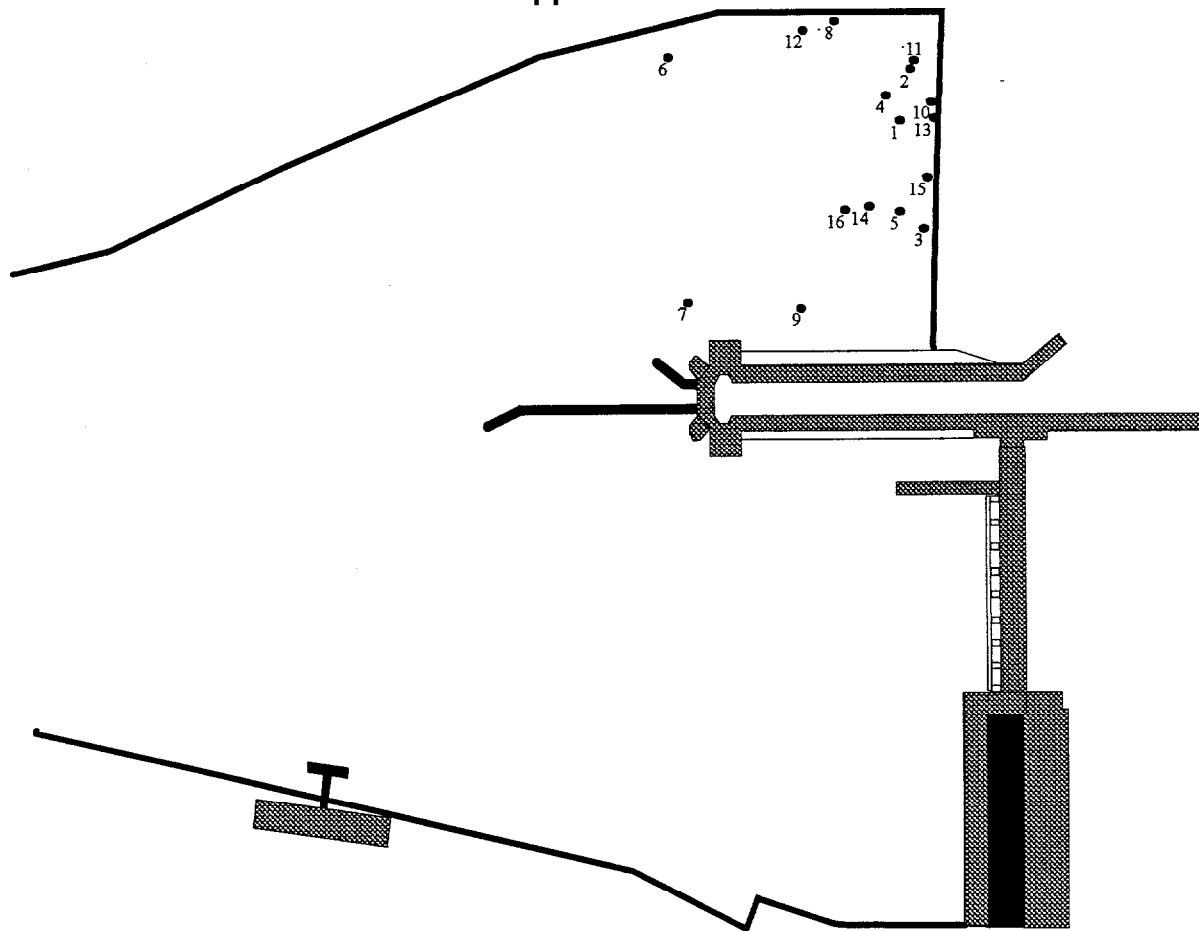
Appendix A

Appendix A, table 1. Roster of northern squawfish implanted with radio-transmitters in the lower Snake River during 1992 and 1993.

Release Date	Transmitter Code	Length (MM)	Release Date
4/26/92	25-I 6	373	Lower Granite Dam
4/26/92	25-I 7	550	Lower Granite Dam
4/26/92	25-I 8	398	Lower Granite Dam
4/26/92	25-21	420	Lower Granite Dam
4/26/92	25-22	402	Lower Granite Dam
4/26/92	25-24	412	Lower Granite Dam
4/26/92	26-I 6	385	Lower Granite Dam
4/26/92	26-I 7	413	Lower Granite Dam
4/26/92	26-I 9	371	Lower Granite Dam
4/26/92	26-20	379	Lower Granite Dam
4/26/92	26-21	354	Lower Granite Dam
4/26/92	26-23	487	Lower Granite Dam
4/26/92	27-I 7	403	Lower Granite Dam
4126192	27-I 8	374	Lower Granite Dam
4/26/92	27-20	377	Lower Granite Dam
4/26/92	27-21	479	Lower Granite Dam
4/26/92	27-23	388	Lower Granite Dam
4/26/92	27-24	449	Lower Granite Dam
4/26/92	28-I 6	516	Lower Granite Dam
4/26/92	28-I 8	368	Lower Granite Dam
4/26/92	28-21	391	Lower Granite Dam
4/26/92	28-22	421	Lower Granite Dam
4/26/92	28-23	391	Lower Granite Dam
4/26/92	28-24	451	Lower Granite Dam
4/26/92	29-I 5	443	Lower Granite Dam
4/26/92	29-I 8	453	Lower Granite Dam
4/26/92	29-21	368	Lower Granite Dam
4/26/92	29-22	415	Lower Granite Dam
4/26/92	29-23	417	Lower Granite Dam
4/26/92	29-24	456	Lower Granite Dam
512 1 /92	21-02	528	Lower Granite Dam
5/2 1 /92	21-09	361	Lower Granite Dam
5/2 1 /92	21-11	377	Lower Granite Dam
5/2 1 /92	21-12	417	Lower Granite Dam
5/2 1 /92	21-13	457	Lower Granite Dam
5/21/92	21-15	426	Lower Granite Dam
5/2 1 /92	21-19	403	Lower Granite Dam
5/2 1/92	21-21	396	Lower Granite Dam
512 1 /92	22-02	435	Lower Granite Dam

Appendix A, table 1 (continued). Roster of northern squawfish implanted with radio-transmitters in the lower Snake River during 1992 and 1993.

Release Date	Transmitter Code	Length (MM)	Release Date
5/2 1 /92	22-09	551	Lower Granite Dam
5/21/92	22-I 2	411	Lower Granite Dam
5/2 1 /92	22-I 3	515	Lower Granite Dam
5/2 1 /92	22-I 4	369	Lower Granite Dam
5/2 1 /92	22-I 6	382	Lower Granite Dam
5/2 1 /92	22-20	385	Lower Granite Dam
5/21/92	22-24	443	Lower Granite Dam
5121192	23-02	384	Lower Granite Dam
5/21/92	23-I 1	363	Lower Granite Dam
5/21/92	23-I 4	415	Lower Granite Dam
5/2 1 /92	23-I 7	400	Lower Granite Dam
5/2 1 /92	23-I 9	384	Lower Granite Dam
5/2 1 /92	23-22	540	Lower Granite Dam
5/21/92	23-25	427	Lower Granite Dam
5/2 1 /92	24-09	436	Lower Granite Dam
5/2 1 /92	24-I 1	387	Lower Granite Dam
5/21/92	24-I 2	435	Lower Granite Dam
5/2 1 /92	24-I 3	372	Lower Granite Dam
5/2 1 /92	24-I 8	463	Lower Granite Dam
5/2 1 /92	24-20	384	Lower Granite Dam
5/2 1 /92	24-2 1	475	Lower Granite Dam
5/2 1 /92	25-01	361	Lower Granite Dam
5/2 1 /92	25-05	399	Lower Granite Dam
5/2 1 /92	26-I 0	377	Lower Granite Dam
5/2 1 /92	27-03	532	Lower Granite Dam
5/2 1 /92	27-08	363	Lower Granite Dam
5/21/92	28-06	522	Lower Granite Dam
5/2 1 /92	28-07	417	Lower Granite Dam
5/2 1/92	29-07	472	Lower Granite Dam
5/2 1 /92	29-08	410	Lower Granite Dam
6/11/92	21-01	372	Almota
6111 /92	23-03	403	Almota
6/11 /92	24-07	367	Almota
6/11/92	26-03	390	Almota
6/11 /92	26-07	416	Almota
6/11 /92	27-I 5	363	Lower Granite Dam
6/11 /92	28-12	362	Almota
6/11 /92	29-03	486	Lower Granite Dam
4/3/93	29-70	427	Boyer Marina

Appendix A, table 1 (continued). Roster of northern squawfish implanted with radio-transmitters in the lower Snake River during 1992 and 1993.

Release Date	Transmitter Code	Length (MM)	Release 'Date
4/3/93	27-68	386	Boyer Marina
4/4/93	31-76	445	Boyer Marina
4/10/93	35-74	417	Boyer Marina
4/10/93	30-72	392	Boyer Marina
4/10/93	28-74	445	Boyer Marina
4/10/93	32-64	384	Boyer Marina
4/10/93	33-70	379	Boyer Marina
4/10/93	34-72	428	Boyer Marina
4/10/93	32-70	425	Boyer Marina
4/10/93	31-68	360	Boyer Marina
4/11/93	26-04	428	Boyer Marina
4/11/93	33-06	575	Boyer Marina
4/11/93	27-70	343	Boyer Marina
4/11/93	34-68	368	Boyer Marina
4111193	30-70	484	Boyer Marina
4/11/93	35-70	370	Boyer Marina
4/11/93	28-76	438	Boyer Marina
4/11/93	31-72	400	Boyer Marina
4/11/93	29-76	464	Boyer Marina
4117193	32-76	346	Boyer Marina
4117193	33-66	347	Boyer Marina
4117193	34-70	405	Boyer Marina
4117193	26-80	347	Boyer Marina
4117193	27-76	390	Boyer Marina
4117193	28-78	362	Boyer Marina
4117193	29-74	385	Boyer Marina
4117193	30-68	390	Boyer Marina
4117193	31-66	355	Boyer Marina
4117193	32-74	354	Boyer Marina
4117193	33-76	345	Boyer Marina
4/17/93	34-66	400	Boyer Marina
4118193	26-70	408	Boyer Marina
4/18/93	35-66	423	Boyer Marina
4/21/93	27-78	375	Boyer Marina
4/21/93	28-72	448	Boyer Marina
4/21/93	29-78	480	Boyer Marina
4/21/93	30-76	365	Boyer Marina
4/21/93	31-70	418	Boyer Marina
4/21/93	32-66	395	Boyer Marina

Appendix A, table 1 (continued). Roster of northern squawfish implanted with radio-transmitters in the lower Snake River during 1992 and 1993.

Release Date	Transmitter Code	Length (MM)	Release Date
5/1/93	33-64	368	Boyer Marina
5/5/93	34-76	545	Boyer Marina
5/5/93	35-64	345	Boyer Marina
5/5/93	26-06	339	Boyer Marina
5/5/93	27-74	350	Boyer Marina
5/1 7193	28-68	451	Boyer Marina
5/20/93	30-74	460	Boyer Marina
5/20/93	31-64	350	Boyer Marina
5120193	32-72	443	Boyer Marina
5/20/93	34-64	344	Boyer Marina
5120193	29-04	356	Boyer Marina
5120193	33-02	485	Boyer Marina
512 1 /93	26-08	360	Boyer Marina
512 1 /93	27-72	377	Boyer Marina
5/2 1 /93	35-72	418	Boyer Marina
613193	33-72	415	Lower Granite Dam
6/1 2193	34-74	415	Lower Granite Dam
6/1 2193	35-76	435	Lower Granite Dam
6112193	28-70	410	Lower Granite Dam
6112193	29-02	457	Lower Granite Dam
6112193	30-78	390	Lower Granite Dam
6/12/93	31-74	408	Lower Granite Dam
6112193	32-02	393	Lower Granite Dam
5113193	28-79	434	Ice Harbor Dam
5113193	27-69	360	Ice Harbor Dam
5113193	26-7 1	385	Ice Harbor Dam
5113193	29-79	410	Ice Harbor Dam
5113193	30-71	370	Ice Harbor Dam
5/1 3193	31-65	434	Ice Harbor Dam
5114193	33-73	445	Ice Harbor Dam
5/1 4193	34-67	418	Ice Harbor Dam
5/1 4193	32-65	515	Ice Harbor Dam
5114193	35-69	545	Ice Harbor Dam
5114193	26-07	413	Ice Harbor Dam
5114193	27-71	480	Ice Harbor Dam
5/28/93	28-69	444	Ice Harbor Dam
5128193	29-73	484	Ice Harbor Dam
5/29/93	30-77	430	Ice Harbor Dam
5/29/93	31-71	478	Ice Harbor Dam
6119193	28-71	357	Ice Harbor Dam

Appendix B

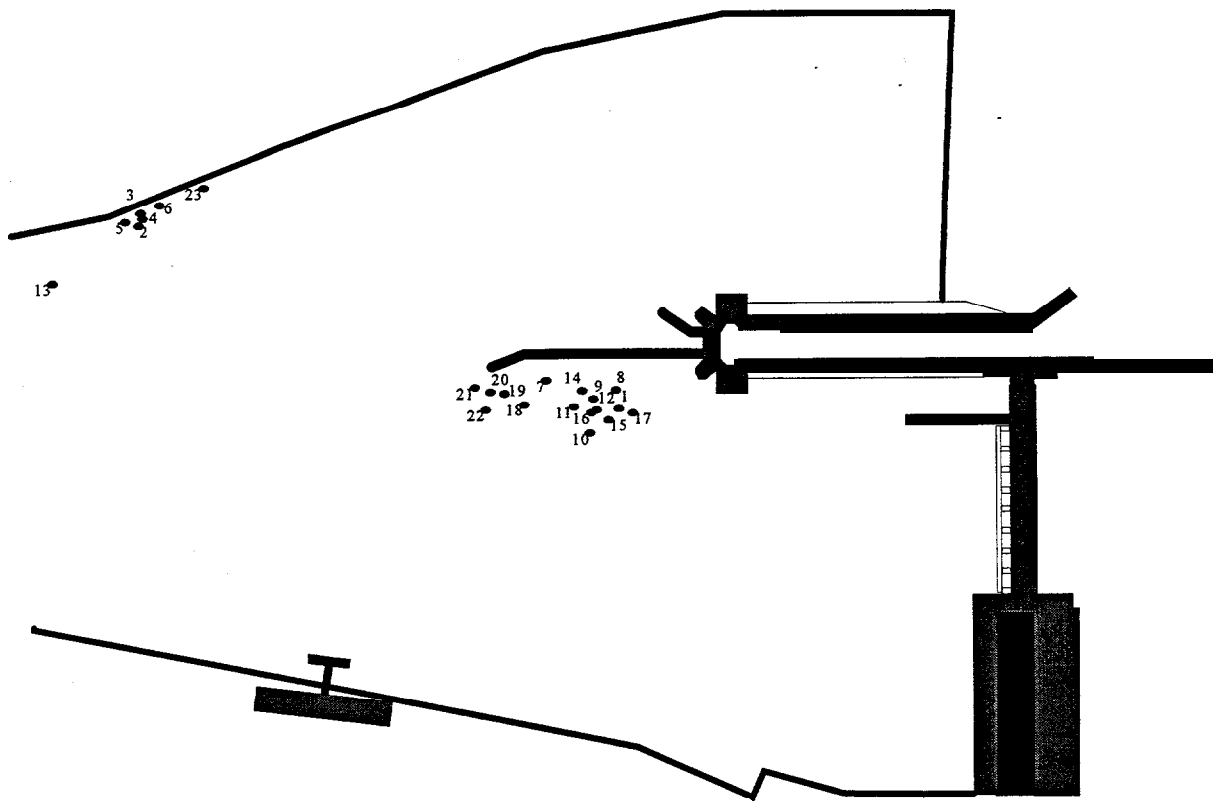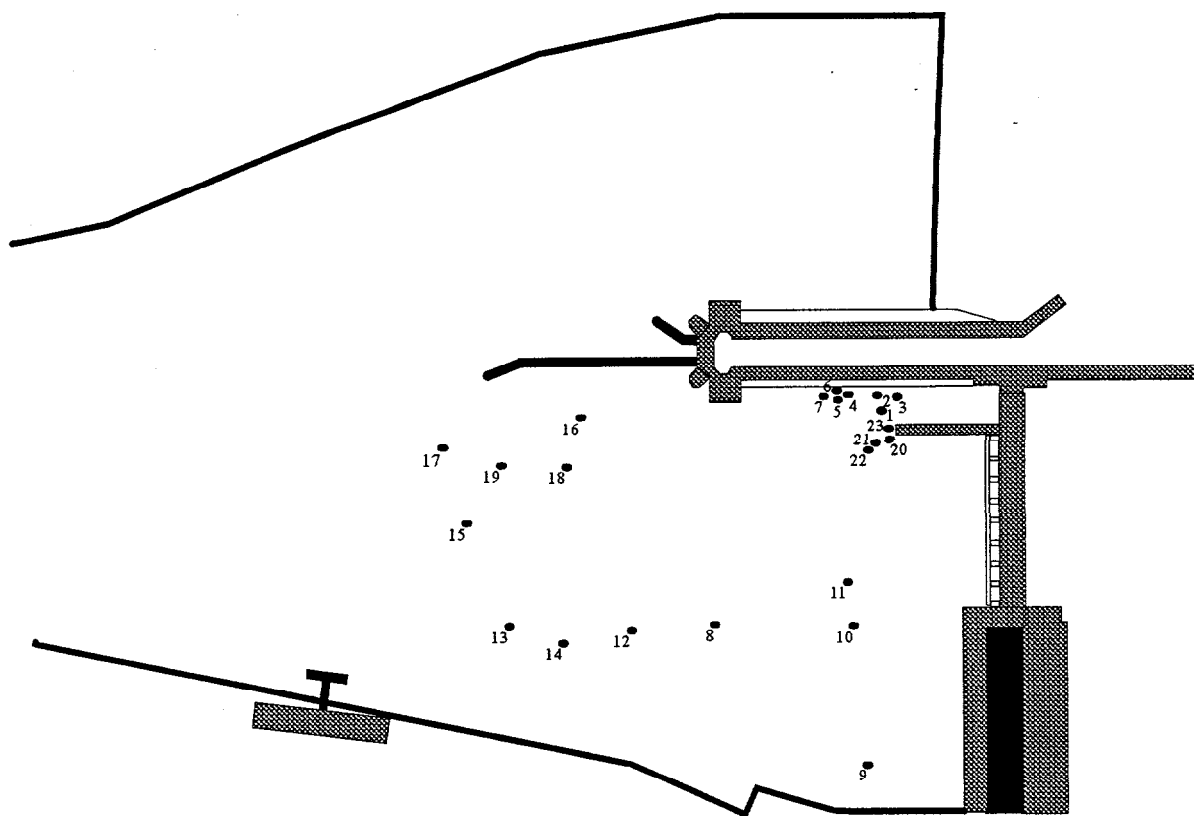| Location	Time
1 - 12:26 pm.	10 - 2:14 am.
2 - 3:06 pm.	11 - 3:25 am.
3 - 4:20 pm.	Spill begins - 4:00 am.
4 - 5:08 pm.	12 - 5:11 am.
5 - 6:11 pm.	Spill ends - 6:00 am.
6 - 7:22 pm.	Sunrise - 6:27 am.
Sunset - 7:32 pm.	13 - 6:54 am.
7 - 8:42 pm.	14 - 8:06 am.
8 - 9:29 pm.	15 - 9:56 am.
9 - 10:37 pm.	16 - 11:05 am.

Appendix B, figure 1. Movements of northern squawfish 26-70 in the tailrace of Lower Granite Dam on June 3, 1993.
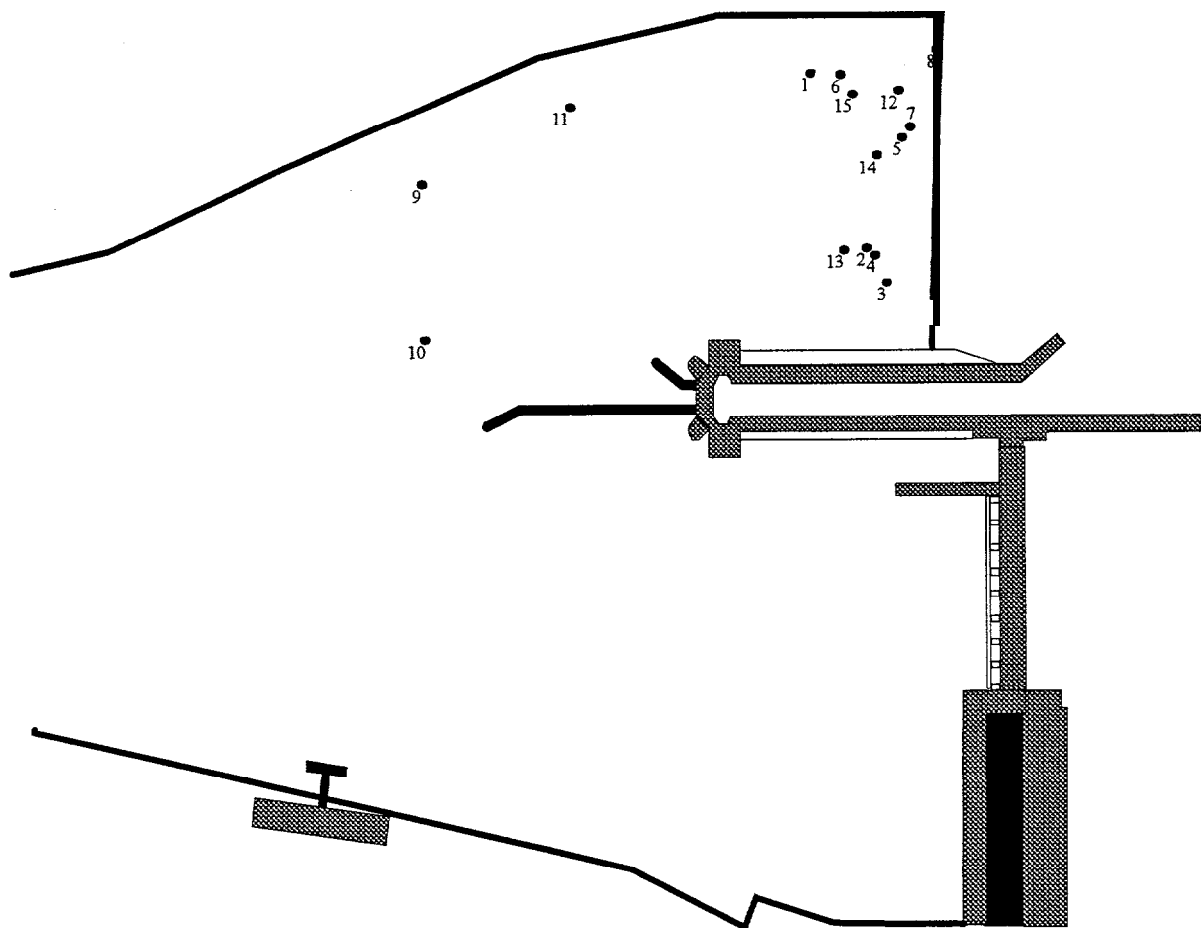
Location Times

l-1:00pm.	Spill begins - 4:00 am.
2 - 3:27 pm.	10 - 4:21 am.
3 - 4:32 pm.	11 - 5:56 am.
4 - 5:16 pm.	Spill ends - 6:00 am.
5 - 6:25 pm.	Sunrise - 6:27 am.
Sunset - 7:32 pm.	12 - 7:06 am.
6 - 7:35 pm.	13 - 8:20 am.
7 - 8:51 pm.	14 - 10:01 am.
8 - 9:41 pm.	15 - 11:23 am.
9 - 2:33 am.	

Appendix B, figure 2. Movements of northern squawfish 34-70 in the tailrace of Lower Granite Dam on June 3, 1993.
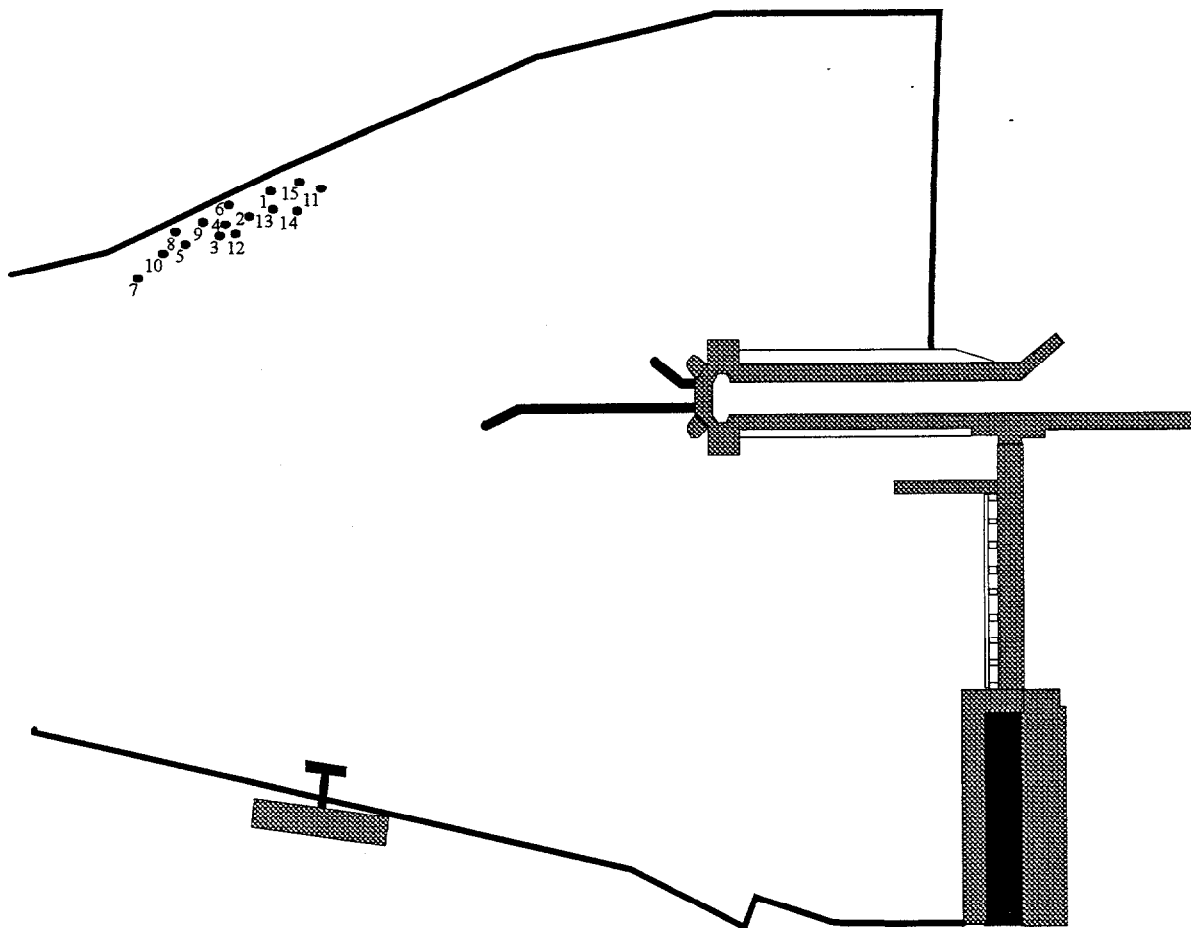
Location Times

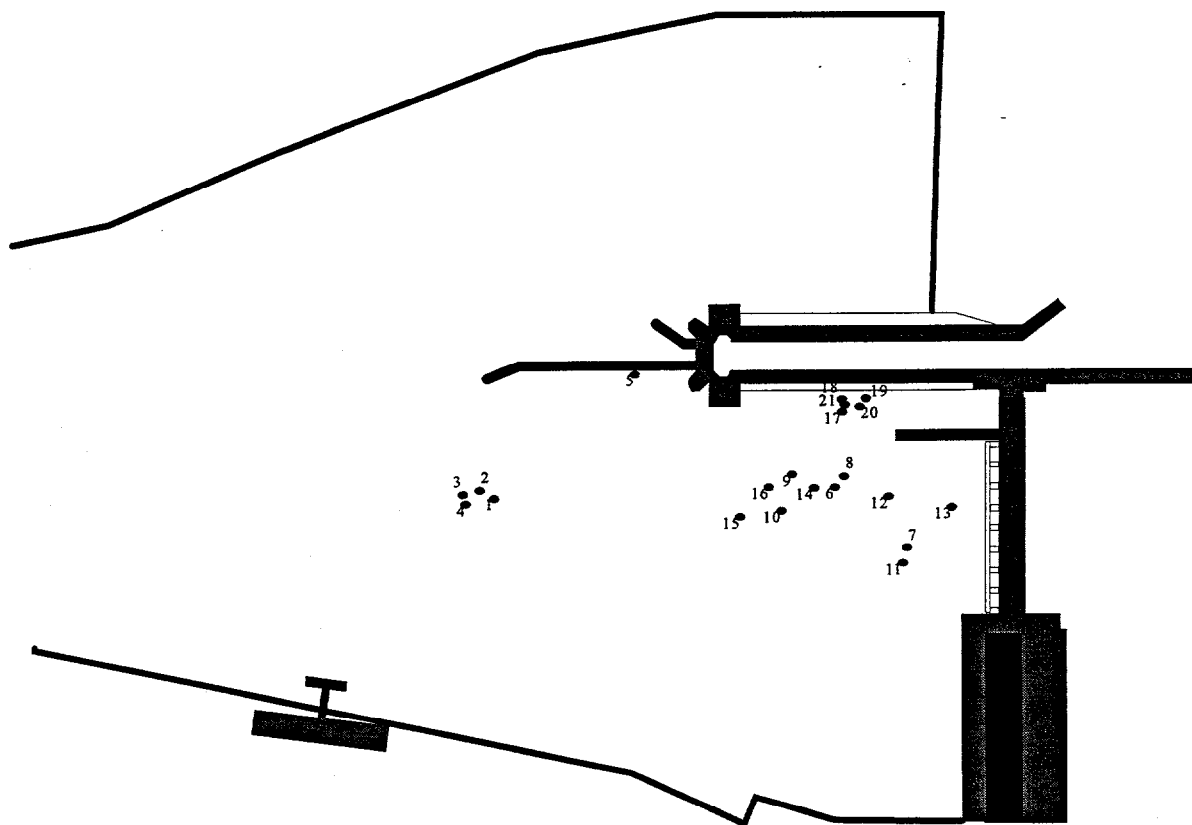|	
1 - 1:15 pm.	10 - 2:40 am.
2 - 3:42 pm.	Spill begins - 4:00 am.
3 - 4:44 pm.	11 - 4:30 am.
4 - 5:32 pm.	Spill ends - 6:00 am.
5 - 6:33 pm.	12 - 6:03 am.
Sunset - 7:32 pm.	Sunrise - 6:27 am.
6 - 7:42 pm.	13 - 7:19 am.
7 - 9:02 pm.	14 - 8:25 am.
8 - 9:50 pm.	15 - 10:07 am.
9 - 23:41 pm.	

Appendix B, figure 3. Movements of northern squawfish 33-66 in the tailrace of Lower Granite Dam on June 3, 1993.

54
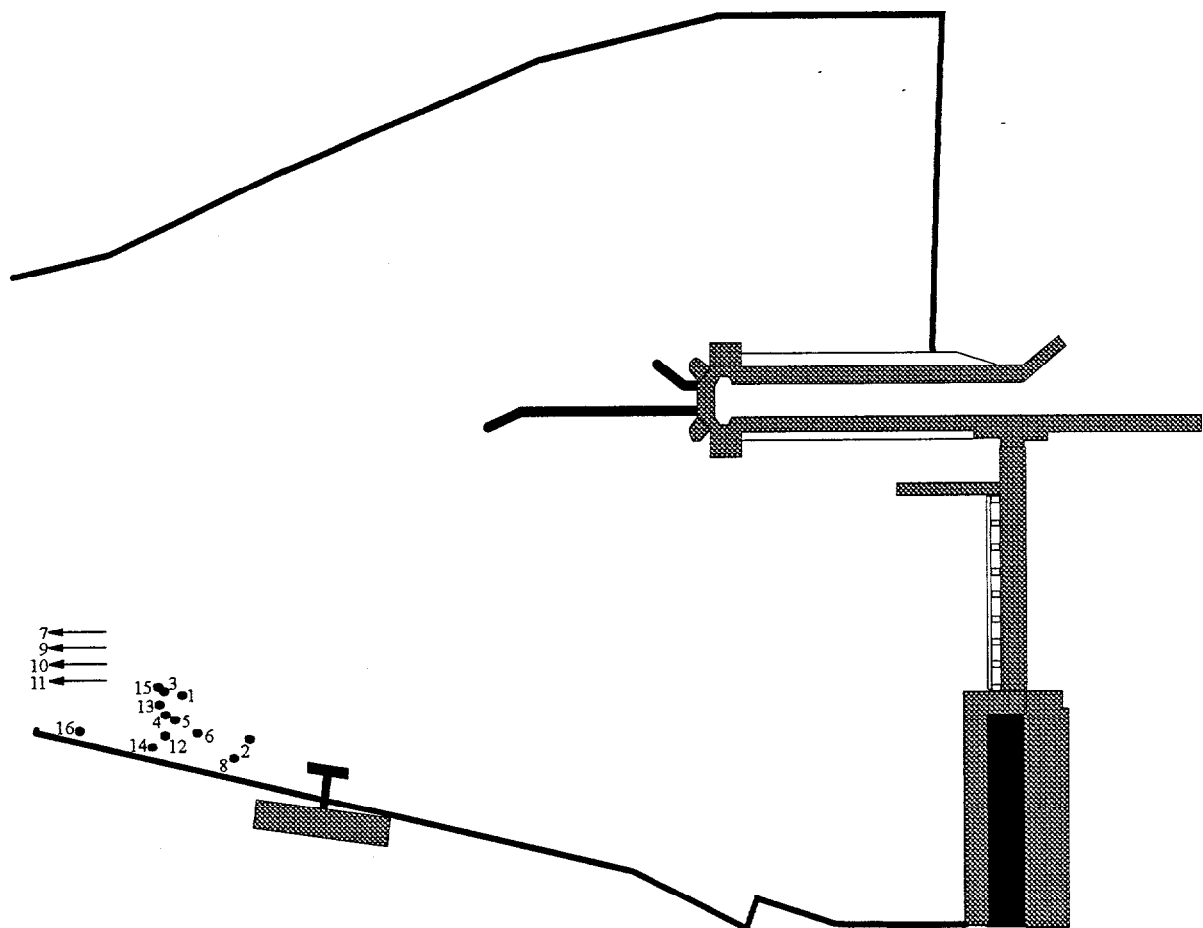
Location Times

|	
1 - 2:35 pm.	10 - 2:51 am.
2 - 4:03 pm.	Spill begins - 4:00 am.
3 - 4:57 pm.	11 - 4:45 am.
4 - 6:40 pm.	Spill ends - 6:00 am.
Sunset - 7:32 pm.	12 - 6:23 am.
5 - 7:52 pm.	Sunrise - 6:27 am.
6 - 9:17 pm.	13 - 7:34 am.
7 - 10:06 pm.	14 - 8:55 am.
8 - 11:52 pm.	15 - 10:20 am.
9 - 1:33 am.	16 - 11:39 am.

Appendix B, figure 4. Movements of northern squawfish 27-70 in the tailrace of Lower Granite Dam on June 3, 1993.

55
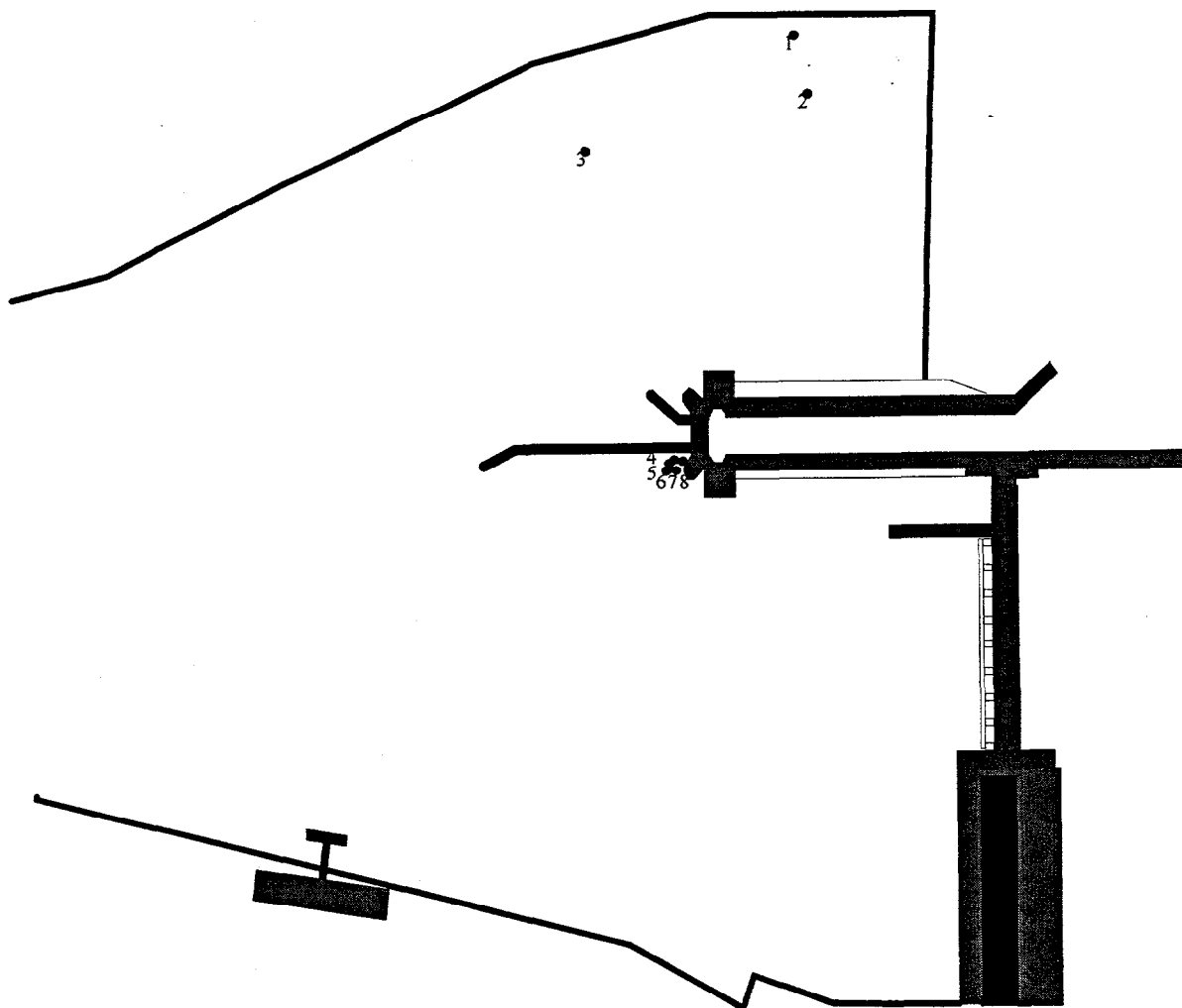
Location Times

|	
1 - 12:36 pm.	Spill begins - 4:00 am.
2 - 5:58 pm.	Spill ends - 6:00 am.
3 - 6:51 pm.	Sunrise - 6:27 am.
Sunset - 7:32 pm.	6 - 6:37 am.
4 - 1:55 am.	7 - 10:32 am.
5 - 3:05 am.	8 - 11:46 am.

Appendix B, figure 5. Movements of northern squawfish 27-78 in the tailrace of Lower Granite Dam on June 3, 1993.
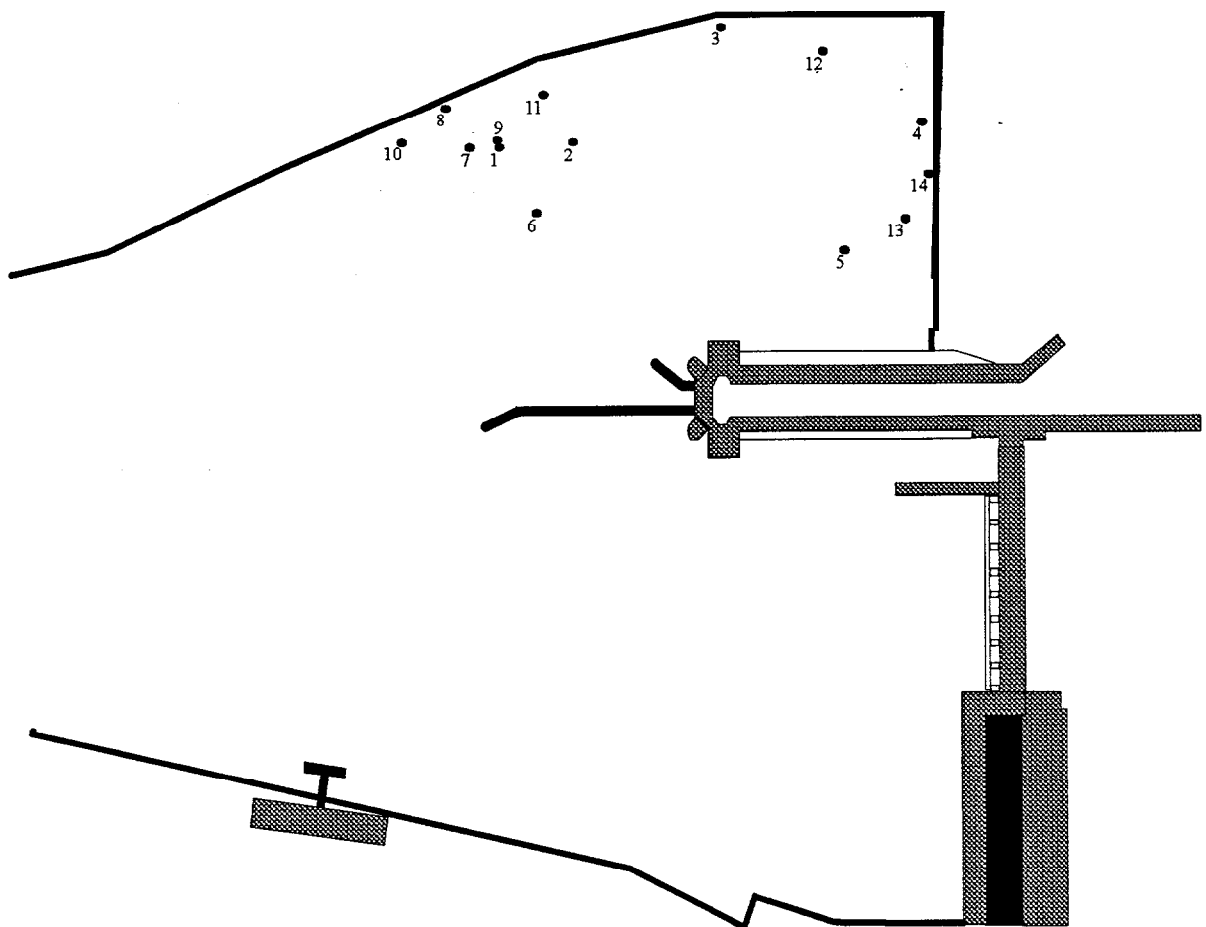
Location Times

1 - 10:48 am.
2 - 11:44 am.
Lock discharge - 12:36 pm.
3 - 12:38 pm.
4 - 2:06 pm.
5 - 2:47 pm.

6 - 3:45 pm.
7 - 4:38 pm.
8 - 5:49 pm.

9 - 6:32 pm.
10 - 7:19 pm.
Sunset - 7:39 pm.

11 - 8:19 pm.
12 - 9:08 pm.
Lock discharge - 9:25 pm.
13 - 12:49 am.
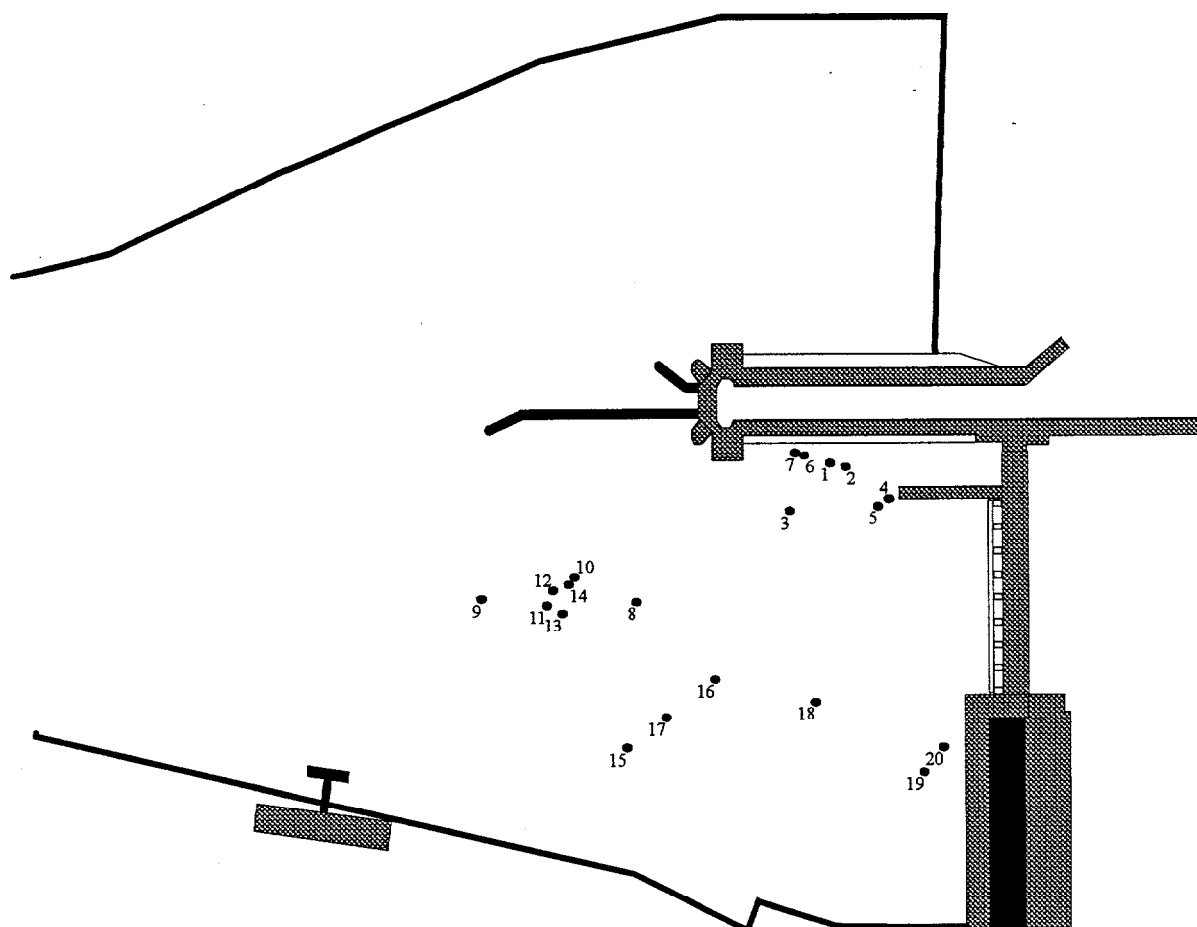14 - 1:49 am.

Appendix B, figure 6. Movements of northern squawfish 27-78 in the tailrace of Lower Granite Dam on June 13, 1993.
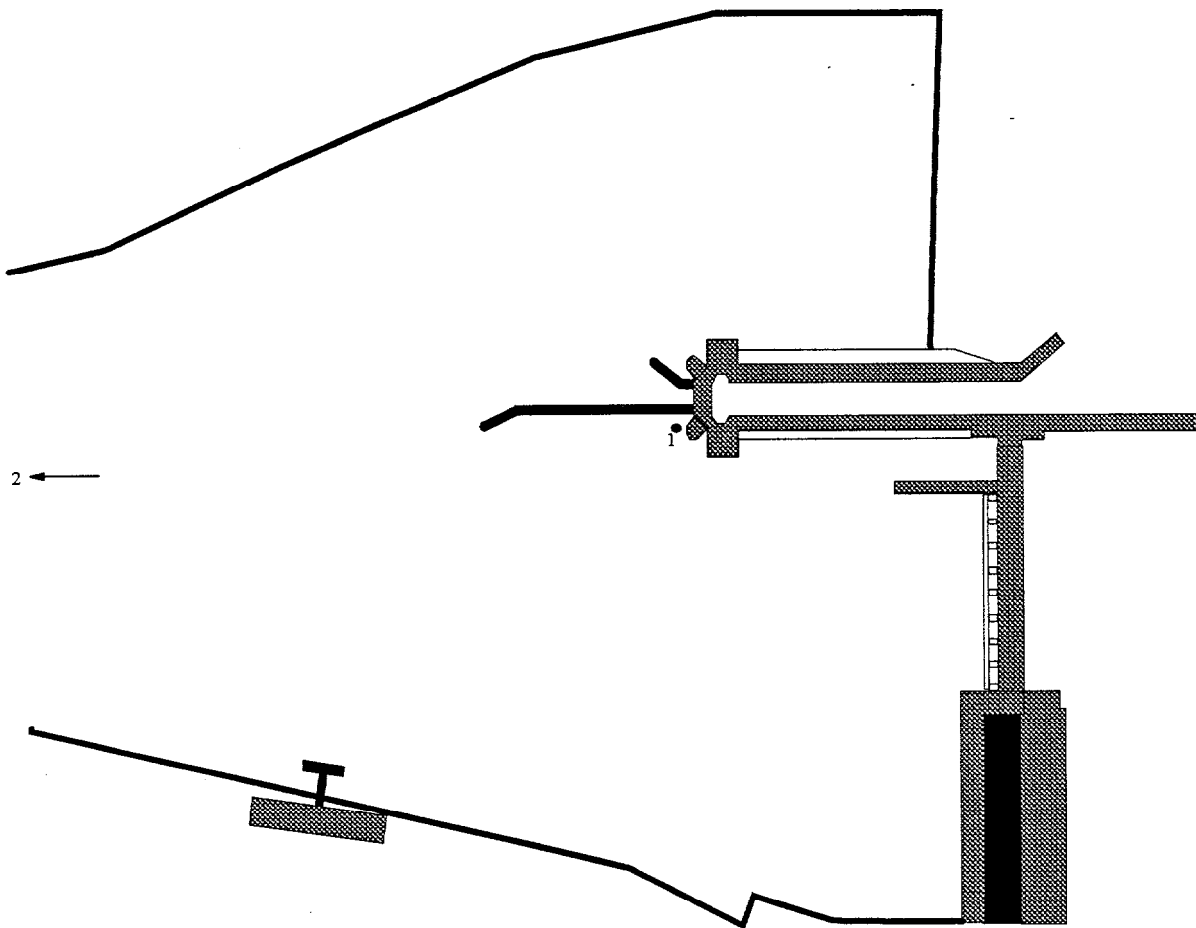
Location Times
1 - 11:37 am.   2 - 1:26 pm.
Lock discharge - 12:36
pm.

Appendix B, figure 7. Movements of northern squawfish 32-72 in the tailrace of Lower Granite Dam on June 13, 1993.
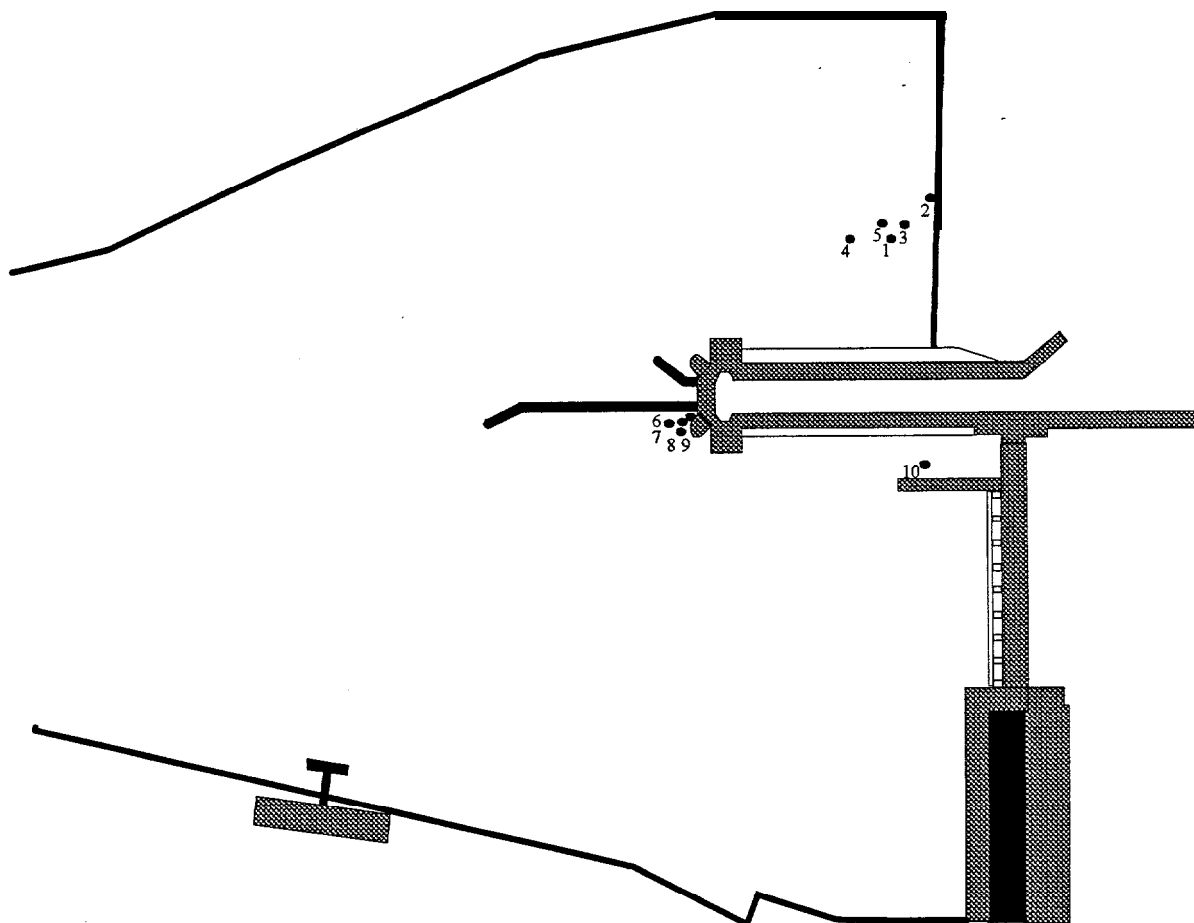
Location Times

1 - 3:13 pm.	6 - 7:44 pm.
2 - 4:00 pm.	7 - 8:56 pm.
3 - 4:55 pm.	Lock discharge - 9:25 pm.
4 - 6:07 pm.	8 - 9:50 pm.
5 - 6:43 pm.	9 - 11:14 pm.
Sunset - 7:39 pm.	10 - 1:28 am.

Appendix B, figure 8. Movements of northern squawfish 28-70 in the tailrace of Lower Granite Dam on June 13, 1993.
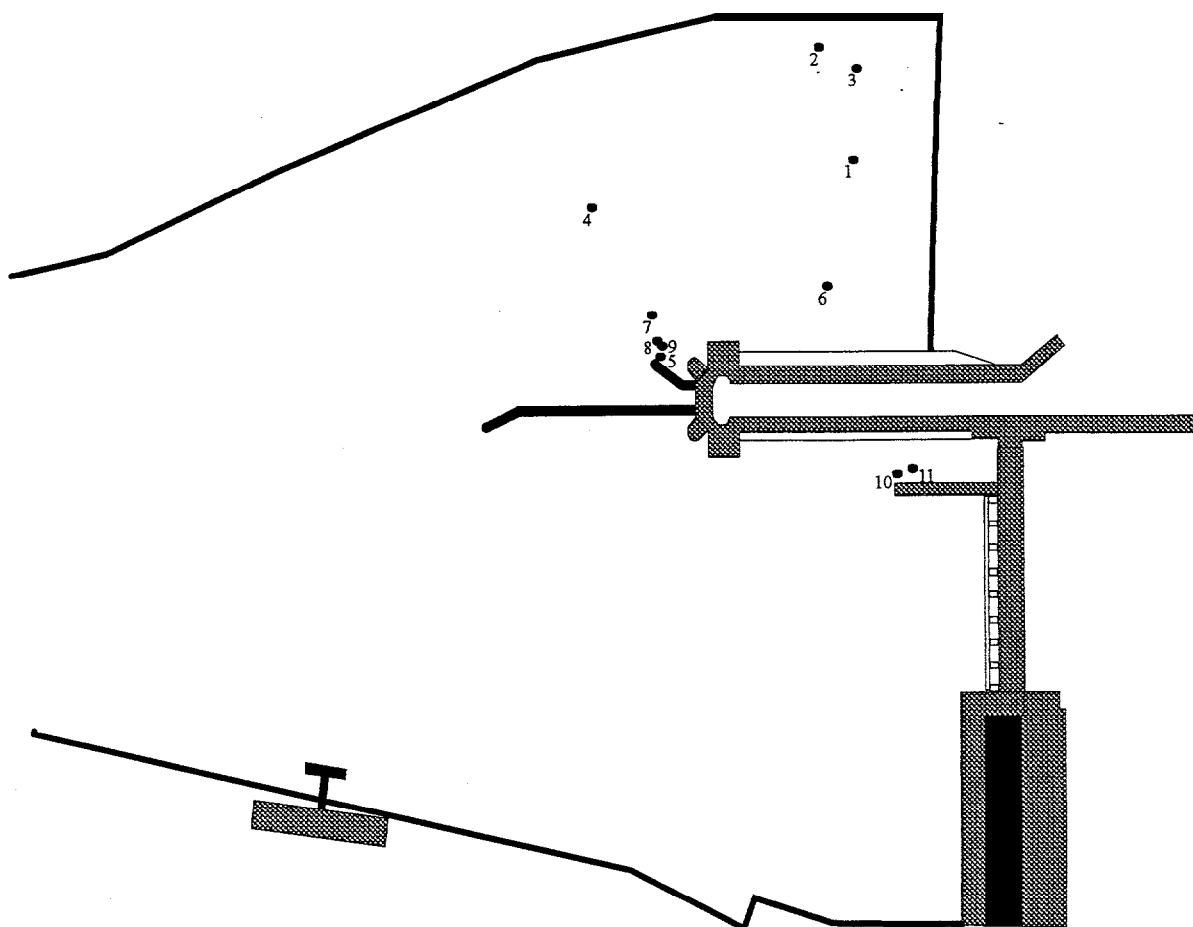
Appendix B, figure 9. Movements of northern squawfish 29-02 in the tailrace of Lower Granite Dam on June 13, 1993.
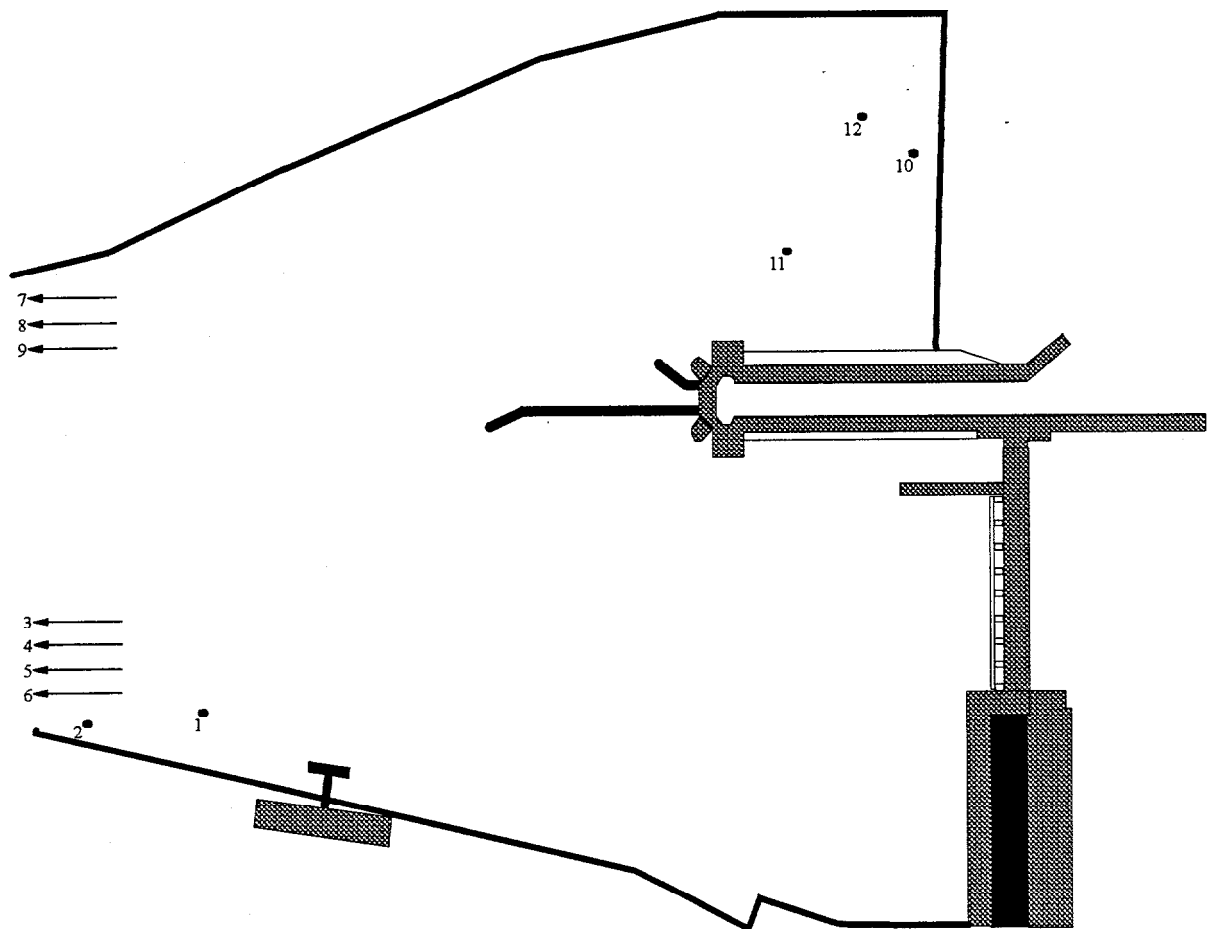
Location Times

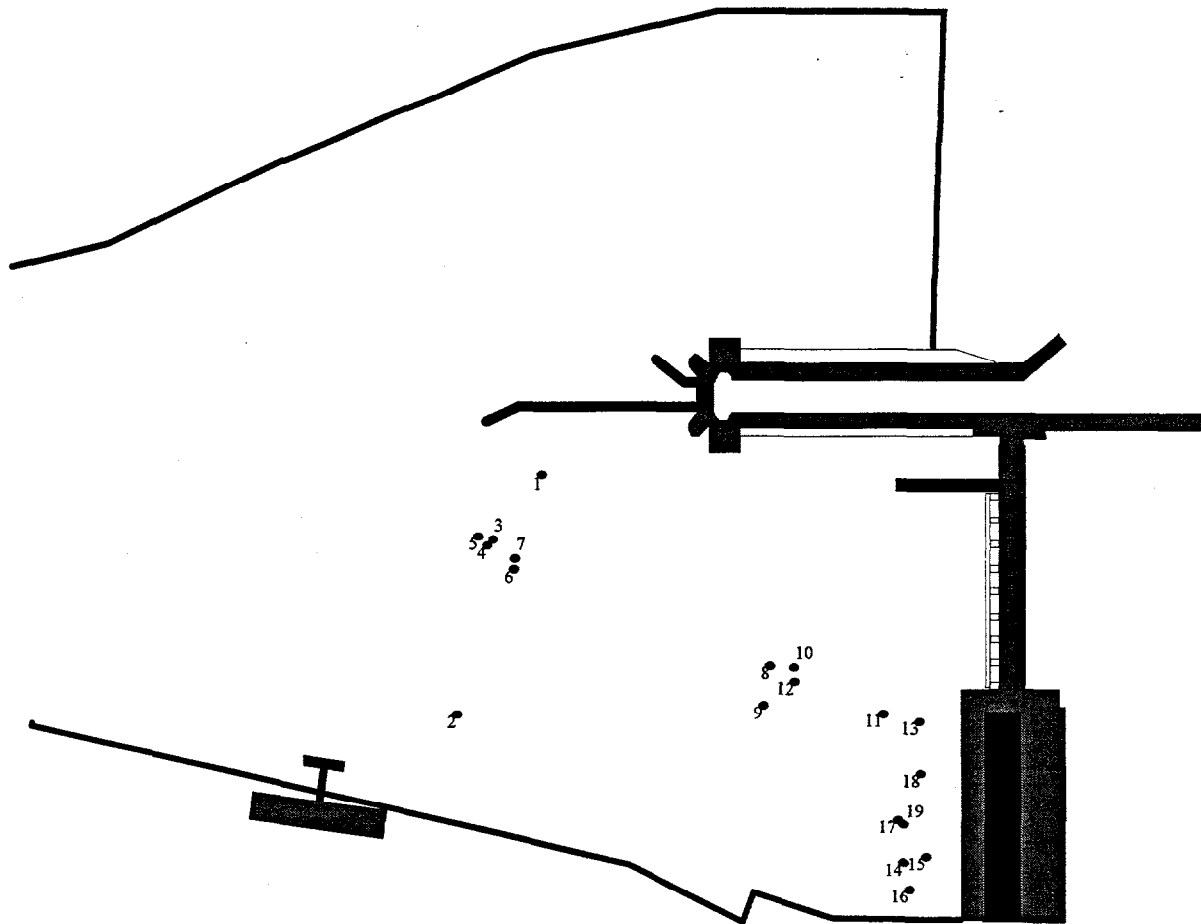|	
1 - 11:11 am.	8 - 6:21 pm.
2 - 12:01 pm.	9 - 6:59 pm.
Lock discharge - 12:36 pm.	Sunset - 7:39 pm.
3 - 1:44 pm.	10 - 8:05 pm.
4 - 2:35 pm.	11 - 9:02 pm.
5 - 3:30 pm.	Lock discharge - 9:25 pm.
6 - 4:16 pm.	12 - 1:56 am.
7 - 5:32 pm.	

Appendix B, figure 10. Movements of northern squawfish 27-70 in the tailrace of Lower Granite Dam on June 13, 1993.
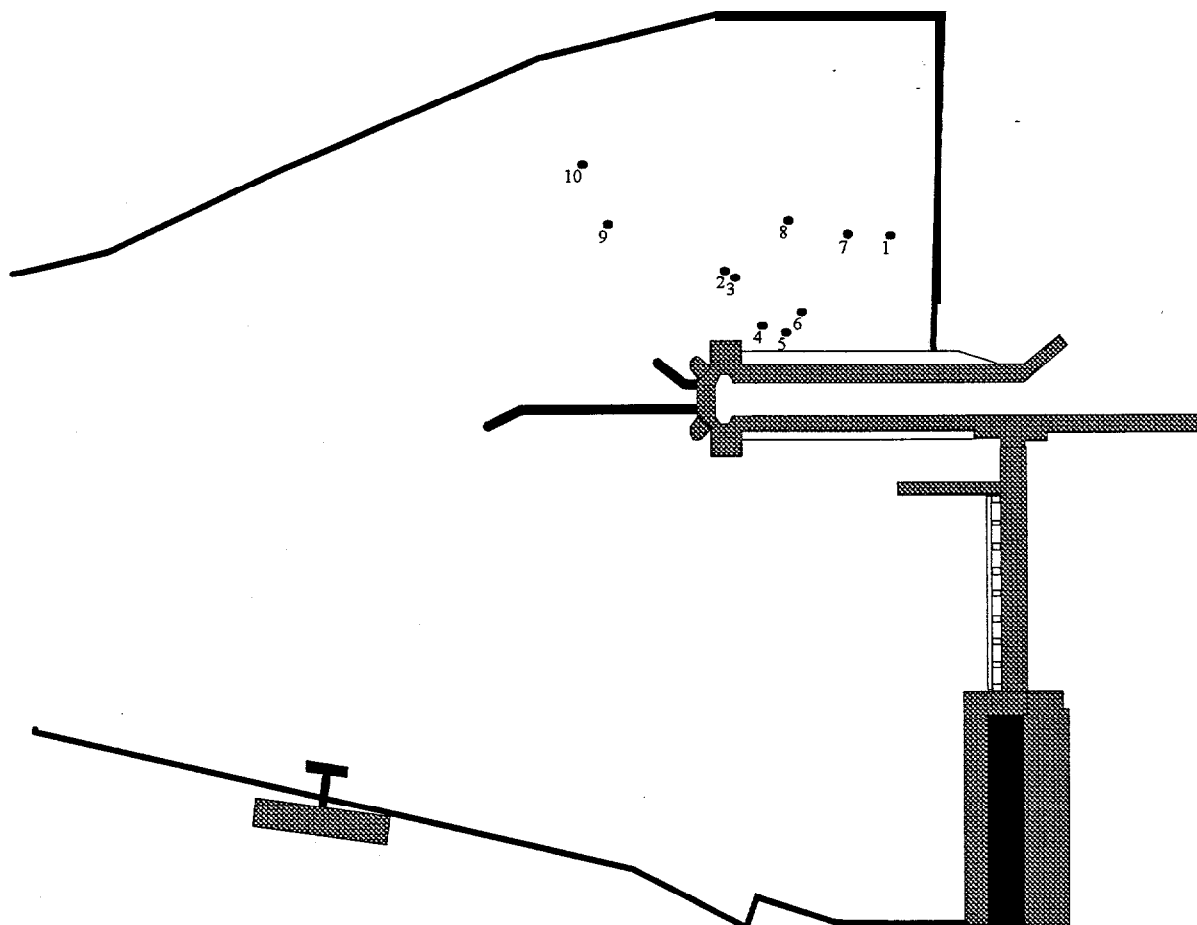
Location Times

1 - 2:01 pm.	Sunset - 7:39 pm.
2 - 3:20 pm.	7 - 7:53 pm.
3 - 4:04 pm.	8 - 9:13 pm.
4 - 5:17 pm.	Lock discharge - 9:25 pm.
5 - 6:12 pm.	9 - 12:57 am.
6 - 6:48 pm.	10 - 2:02 am.

Appendix B, figure 11. Movements of northern squawfish 32-02 in the tailrace of Lower Granite Dam on June 13, 1993.
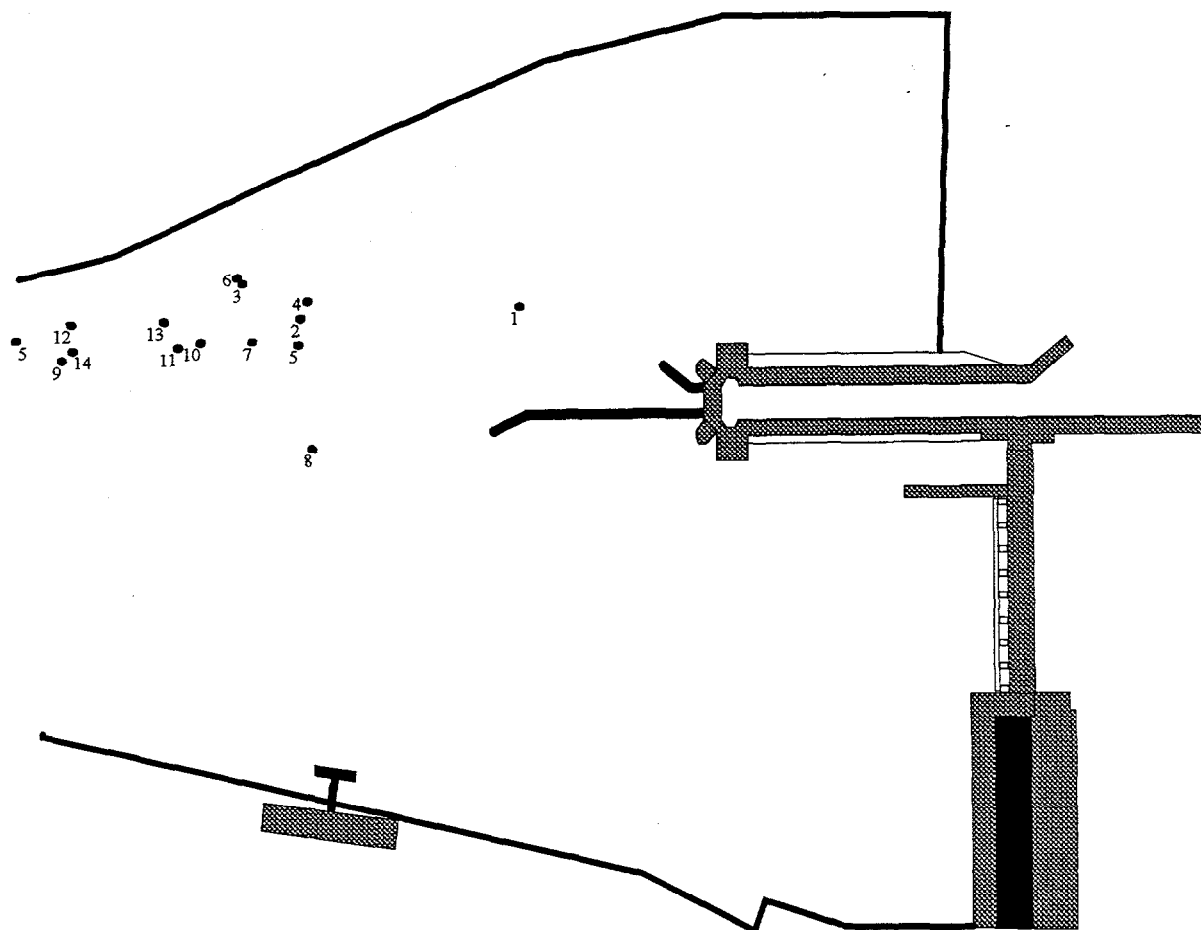
Location Times

|	
1 - 9:02 pm.	9 - 5:57 am.
Lock discharge - 9:48 pm.	Sunrise - 6:25 am.
2 - 10:13 pm.	10 - 6:55 am.
3 - 11:24 pm.	11 - 8:01 am.
4 - 12:20 am.	12 - 9:14 am.
5 - 1:24 am.	13 - 11:52 am.
6 - 2:36 am.	Lock discharge - 11:53 am.
7 - 3:39 am.	14 - 12:48 pm.
8 - 4:41 am.	15 - 1:55 pm.

    Appendix B, figure 12. Movements of northern squawfish 31-72 in the tailrace of Lower Granite Dam on June 24, 1993.

63
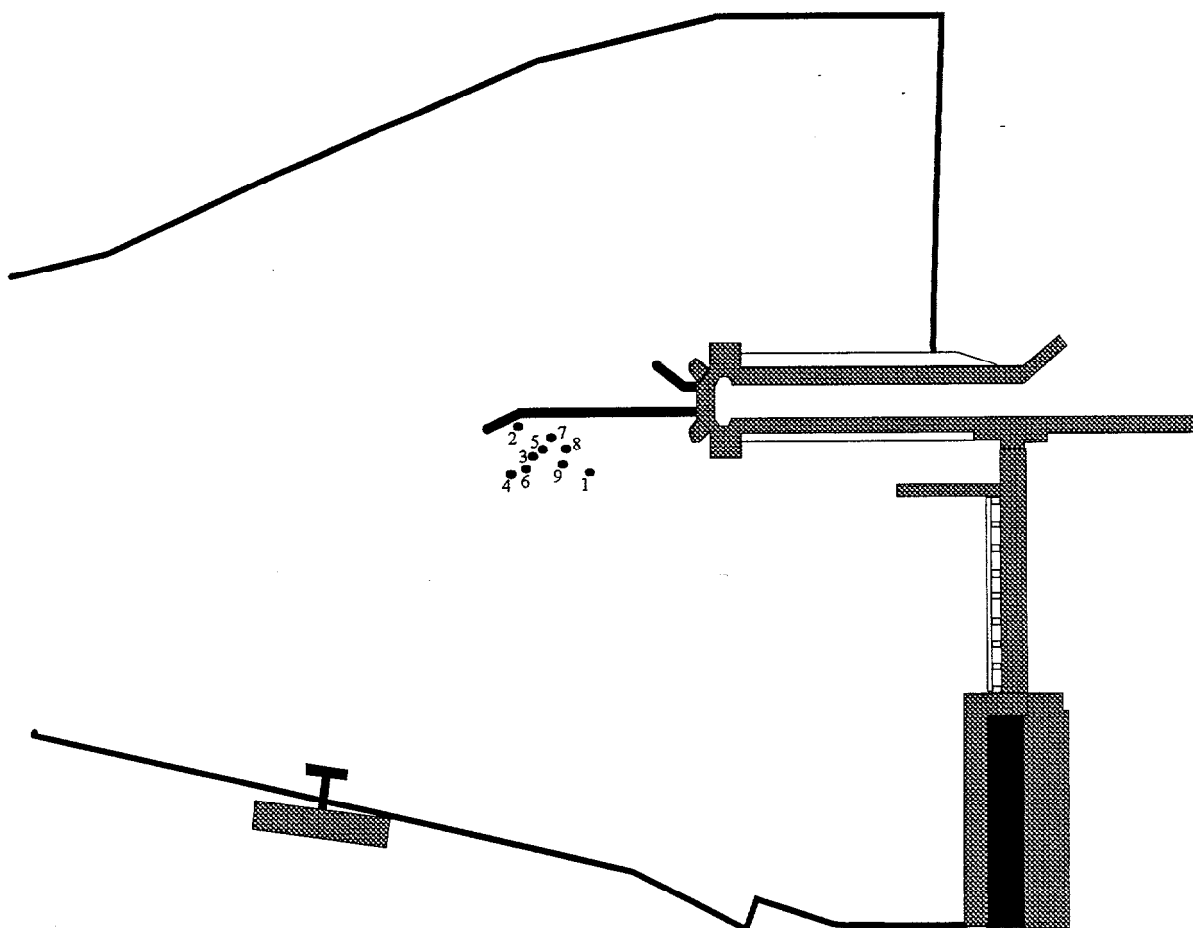
Location Times

|	
Sunrise - 6:25 am.	Lock discharge - 4:40 pm.
1 - 6:45 am.	6 - 5:22 pm.
2 - 7:21 am.	7 - 6:17 pm.
3 - 8:29 am.	8 - 7:00 pm.
Lock discharge - 11:53 am.	Lock discharge - 7:06 pm.
4 - 3:10 pm.	Sunset - 7:43 pm.
5 - 4:06 pm.	9 - 7:59 pm.

Appendix B, figure 13. Movements of northern squawfish 28-70 in the tailrace of Lower Granite Dam on June 24, 1993.

Location Times

1 - 9:25 pm.	14 - 11:37 am.
Lock discharge - 9:48 pm.	Lock discharge - 11:53 am.
2 - 1 1:28 pm.	15 - 12:17 pm.
3 - 12:26 am.	16 - 1:11 pm.
4 - 1:28 am.	17 - 2:15 pm.
5 - 2:40 am.	18 - 3:53 pm.
6 - 3:43 am.	Lock discharge - 4:40 pm.
7 - 4:53 am.	19 - 4:57 pm.
8 - 6:09 am.	20 - 6:01 pm.
Sunrise - 6:25 am.	21 - 6:20 pm.
9 - 7:02 am.	22 - 7:04 pm.
IO- 8:11 am.	Lock discharge - 7:06 pm.
11 - 9:27 am.	Sunset - 7:43 pm.
12 - 10:22 am.	23 - 8:07 pm.
13 - 11:18 am.	

Appendix B, figure 14. Movements of northern squawfish 33-66 in the tailrace of Lower Granite Dam on June 24, 1993.
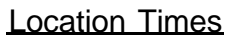
65

Appendix B, figure 15. Movements of northern squawfish 32-66 in the tailrace of Lower Granite Dam on June 24, 1993.

<u>Location Times</u>

1 - 9:39 pm.

Lock discharge - 9:48 pm.

2 - 12:01 am.
3 - 1:00 am.
4 - 1:48 am.
5 - 3:27 am.

6 - 4:17 am.
7 - 5:25 am.
Sunrise - 6:25 am.
8 - 6:26 am.

9 - 8:23 am.
10 - 9:57 am.
11 - 10:45 am.
12 - 11:43 am.

Lock discharge - 11:53 am.

13 - 12:24 pm.

14 - 1:16 pm.
15 - 2:23 pm.
16 - 4:00 pm.
Lock discharge - 4:40 pm.
17 - 5:03 pm.
18 - 5:48 pm.
19 - 6:44 pm.
Lock discharge - 7:06 pm.
20 - 7:30 pm.
Sunset - 7:43 pm.
21 - 8:18 pm.

Appendix B, figure 16. Movements of northern squawfish 34-74 in the tailrace of Lower Granite Dam on June 24, 1993.

67
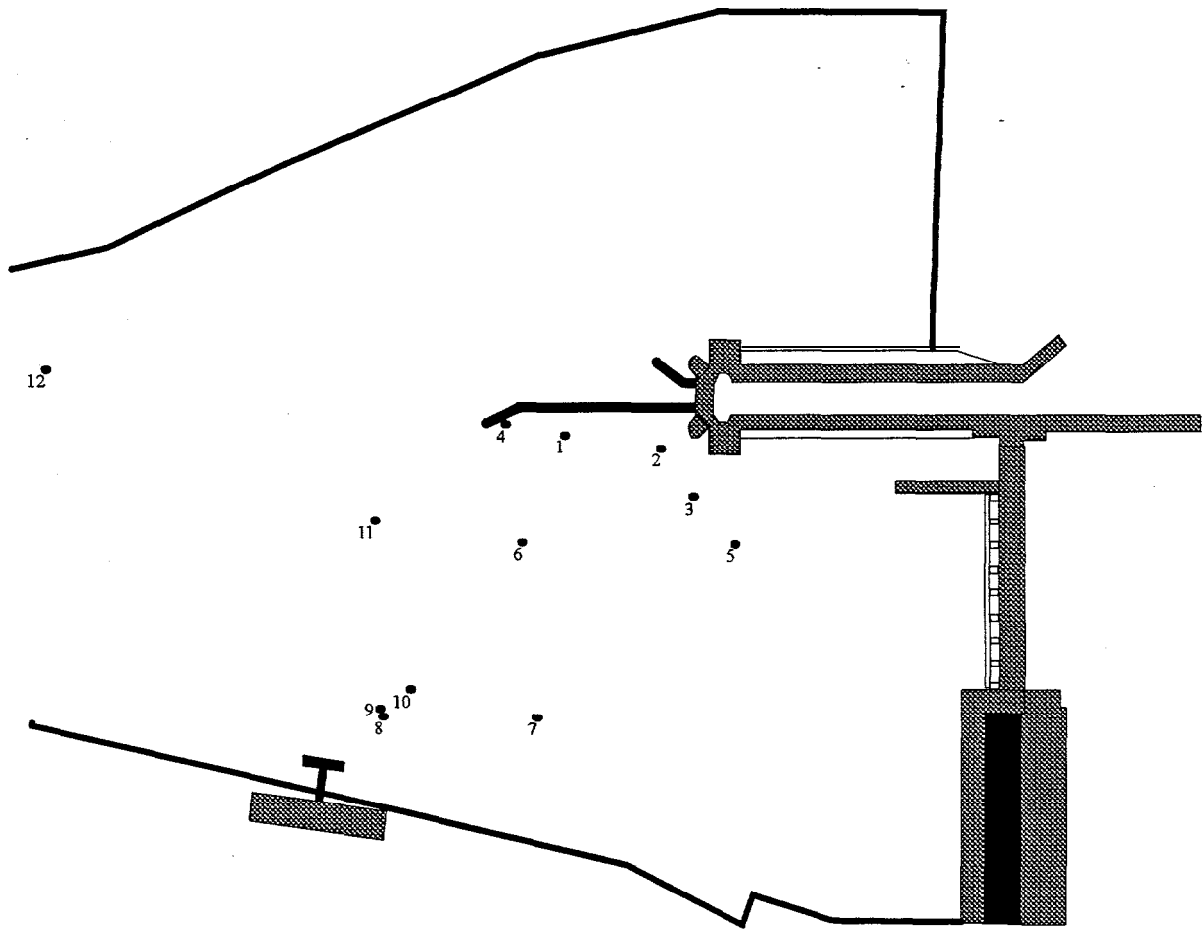
Location Times

1 - 9:30 pm.	7 - 9:39 am.
Lock discharge - 9:48 pm.	8 - 10:33 am.
2 - 11:56 pm.	9 - 11:25 am.
3 - 12:56 am.	Lock discharge - 11:53 am.
4 - 1:54 am.	10 - 12:02 pm.
5 - 3:04 am.	11 - 12:57 pm.
6 - 4:00 am.	12 - 2:03 pm.
Sunrise - 6:25 am.	

Appendix B, figure 17. Movements of northern squawfish 35-74 in the tailrace of Lower Granite Dam on June 24, 1993,

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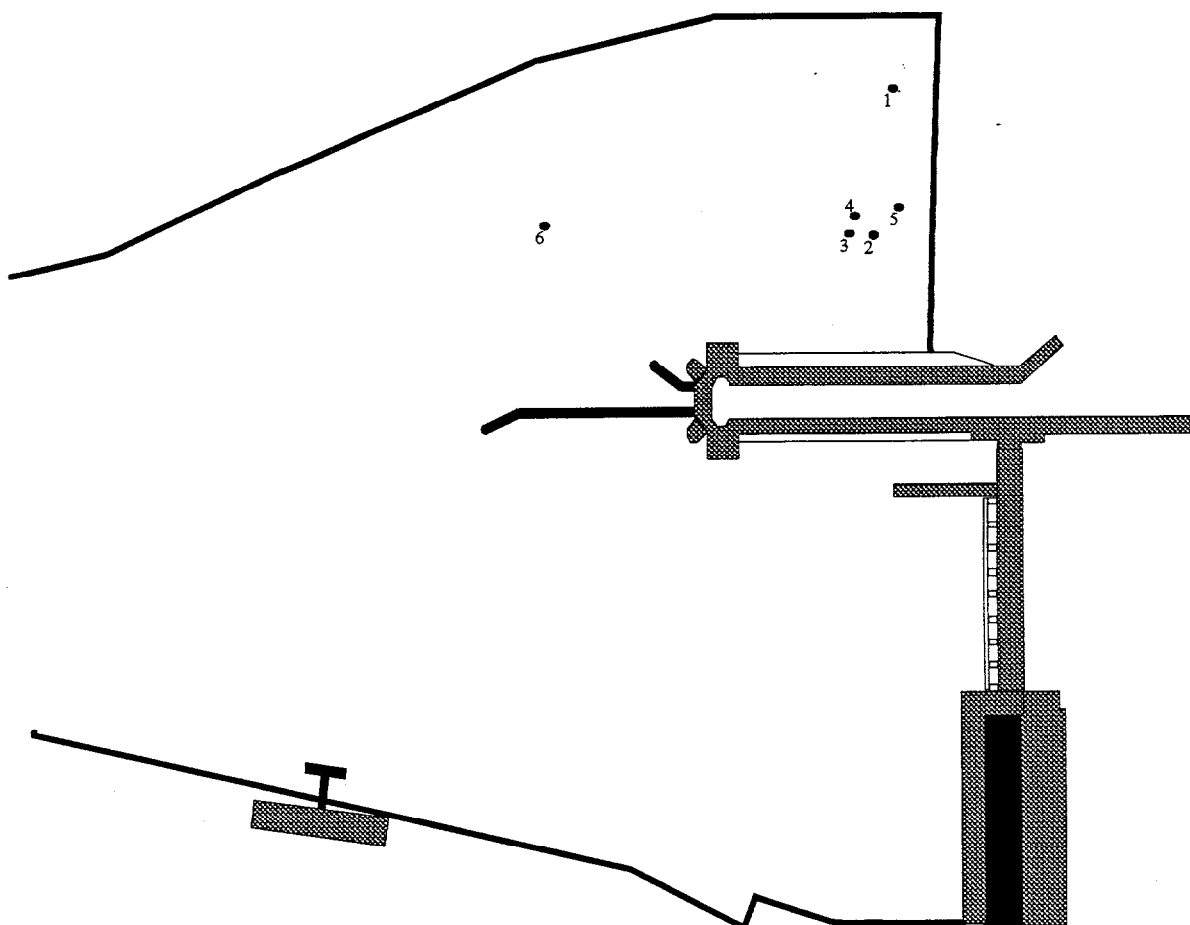
Location Times

1 - 3:35 pm.   5 - 6:53 pm.
2 - 4:15 pm.   Lock discharge - 7:06 pm.
Lock discharge - 4:40 pm.   Sunset - 7:43 pm.
3 - 5:11 pm.   6 - 7:53 pm.
4 - 6:08 pm.

Appendix B, figure 18. Movements of northern squawfish 31-76 in the tailrace of Lower Granite Dam on June 24, 1993.

Appendix B, figure 19. Movements of northern squawfish 26-08 in the tailrace of Lower Granite Dam on July 8, 1993.
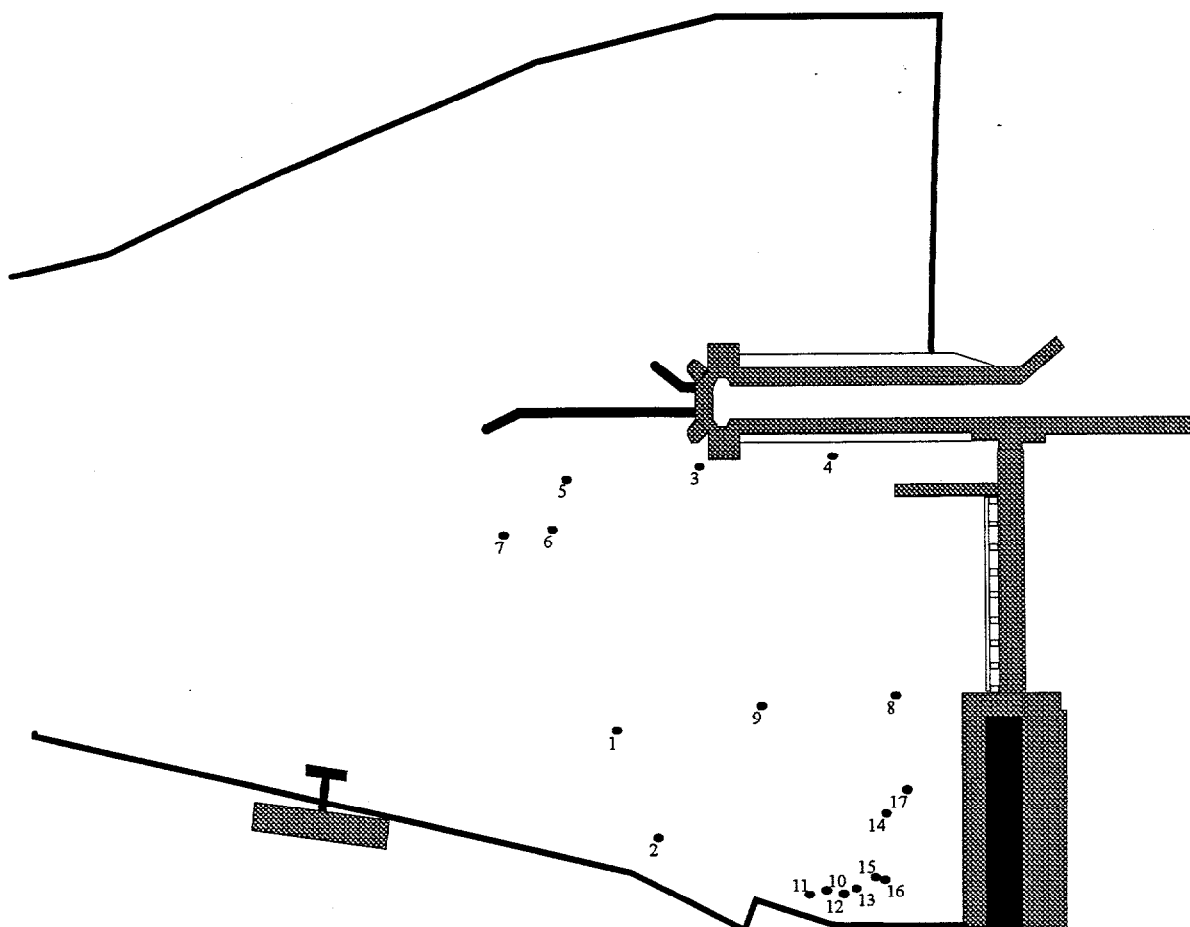
Location Times

1 - 7:12 pm.	Sunrise - 6:33 am.
Sunset - 7:40 pm.	10 - 8:21 am.
2 - 8:03 pm.	11 - 10:40 am.
Lock discharge - 8:38 pm.	12 - 11:40 am.
3 - 11:30 pm.	13 - 12:27 pm.
4 - 12:17 am.	14 - 1:39 pm.
5 - 2:27 am.	15 - 2:25 pm.
6 - 3:19 am.	Lock discharge - 3:34 pm.
7 - 4:32 am.	16 - 4:55 pm.
8 - 5:44 am.	17 - 6:02 pm.
9 - 6:31 am.	

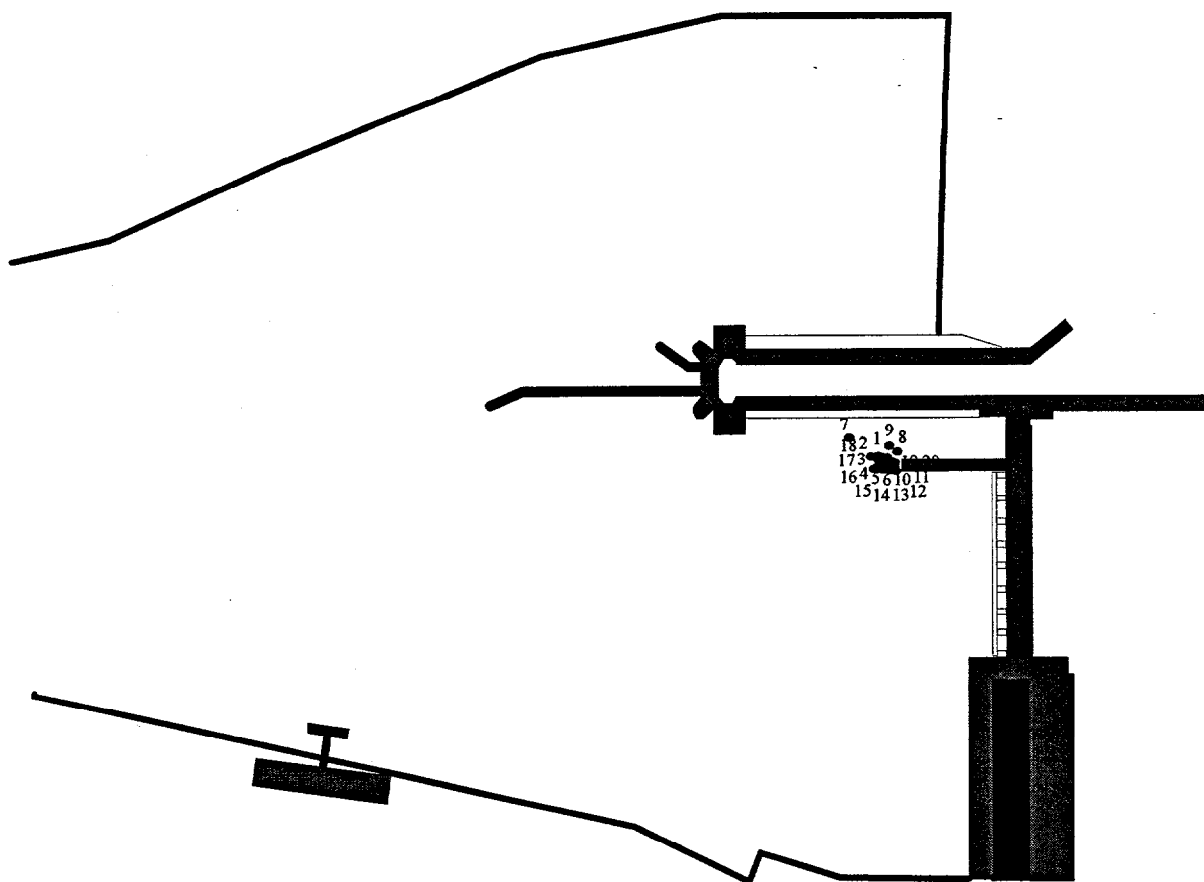Appendix B, figure 20. Movements of northern squawfish 28-76 in the tailrace of Lower Granite Dam on July 8, 1993.

Appendix B, figure 21. Movements of northern squawfish 33-66 in the tailrace of Lower Granite Dam on July 8, 1993.

72
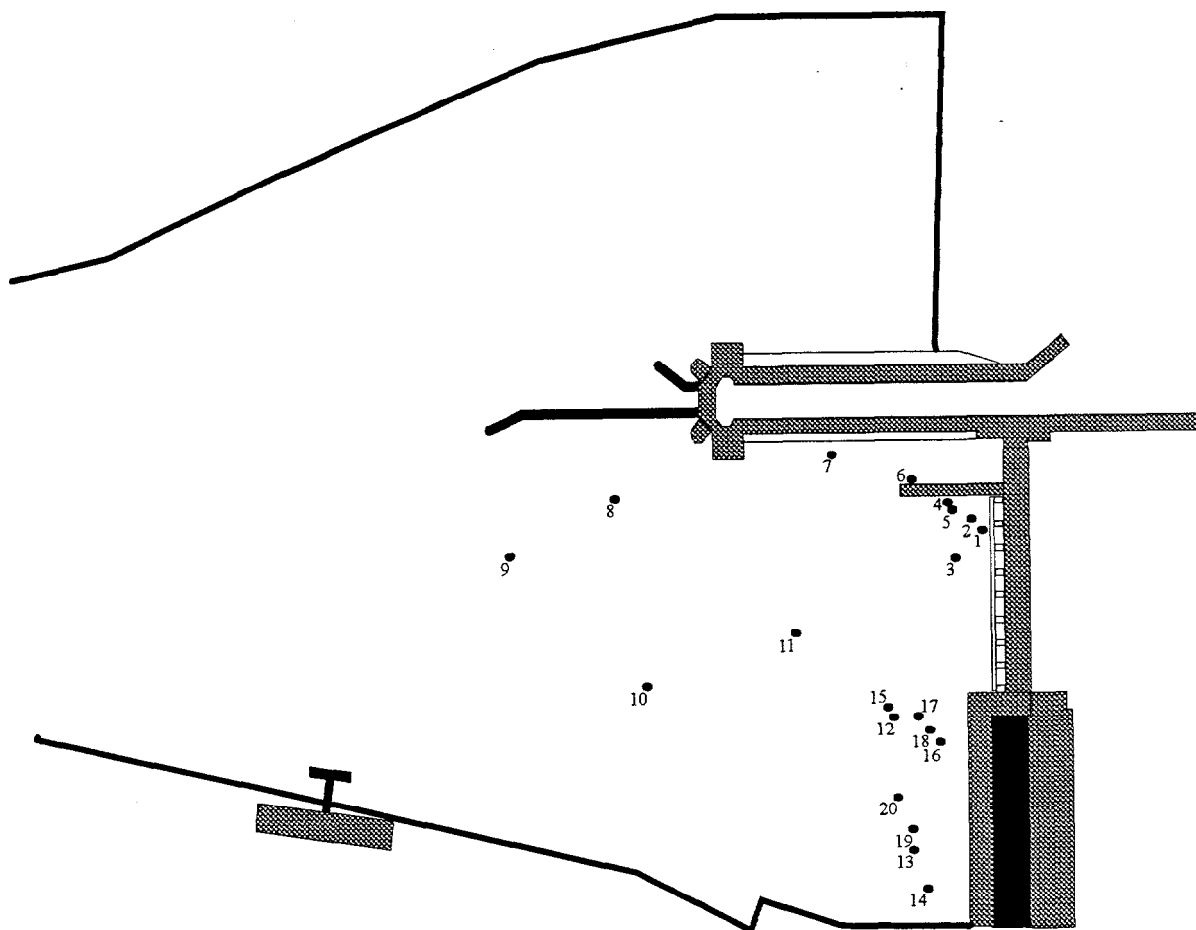
Location Times

|	
1 - 7:02 pm.	11 - 6:21 am.
Sunset - 7:40 pm.	Sunrise - 6:33 am.
2 - 7:54 pm.	12 - 7:24 am.
Lock discharge - 8:38 pm.	13 - 9:09 am.
3 - 9:04 pm.	14 - 10:12 am.
4 - 11:12 pm.	15 - 11:11 am.
5 - 12:06 am.	16 - 12:07 pm.
6 - 1:10 am.	17 - 1:13 pm.
7 - 2:09 am.	18 - 2:09 pm.
8 - 3:14 am.	Lock discharge - 3:34 pm.
9 - 4:22 am.	19 - 5:26 pm.
10 - 5:28 am.	20 - 6:33 pm.

Appendix B, figure 22. Movements of northern squawfish 27-74 in the tailrace of Lower Granite Dam on July 8, 1993.
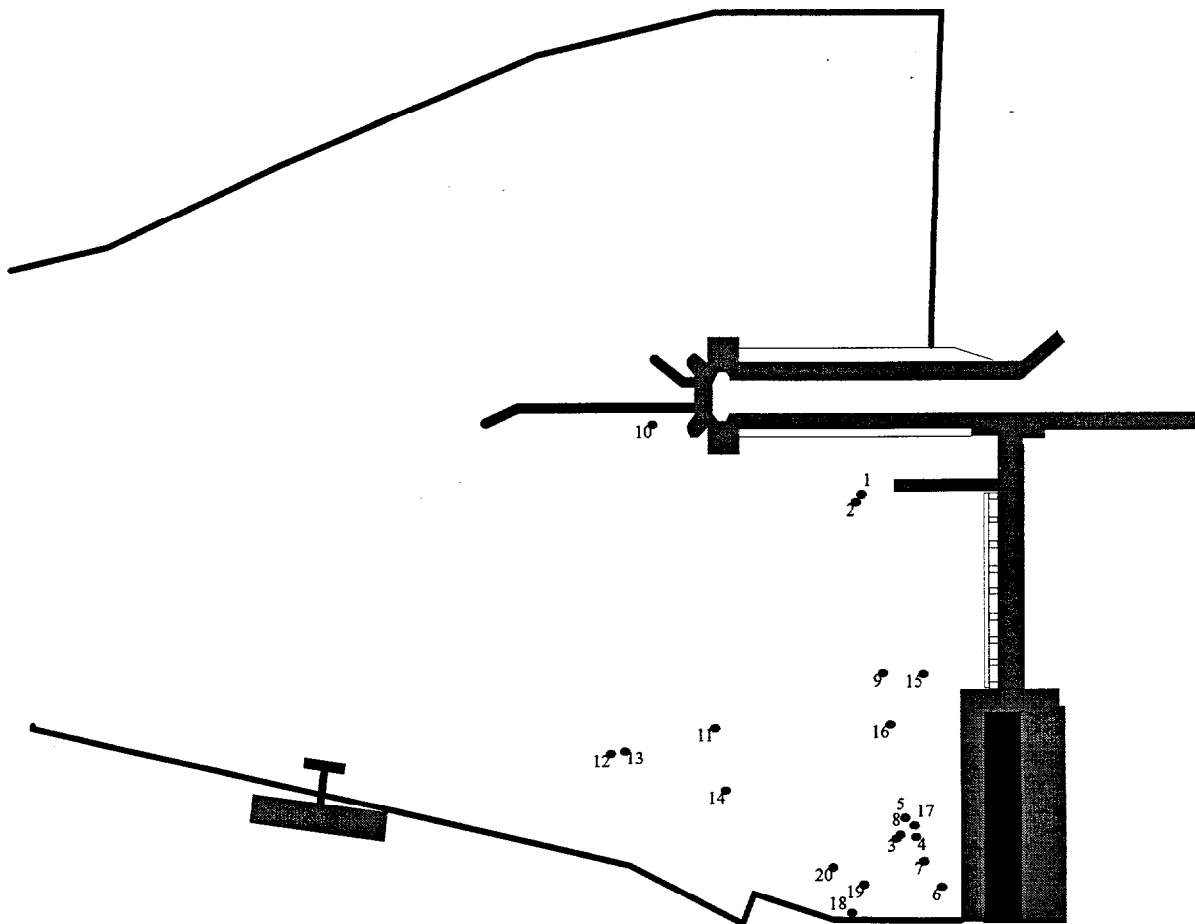
Location Times

1 - 7:29 pm.	10 - 6:56 am.
Sunset - 7:40 pm.	11 - 8:33 am.
2 - 7:57 pm.	12 - 9:47 am.
Lock discharge - 8:38 pm.	13 - 10:47 am.
3 - 11:18 pm.	14 - 11:45 am.
4 - 12:09 am.	15 - 12:40 pm.
5 - 1:14 am.	16 - 1:48 pm.
6 - 2:38 am.	17 - 3:00 pm.
7 - 3:33 am.	Lock discharge - 3:34 pm.
8 - 4:45 am.	18 - 4:24 pm.
9 - 5:57 am.	19 - 5:30 pm.
Sunrise - 6:33 am.	20 - 6:23 pm.

Appendix B, figure 23. Movements of northern squawfish 35-72 in the tailrace of Lower Granite Dam on July 8, 1993.

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Location Times

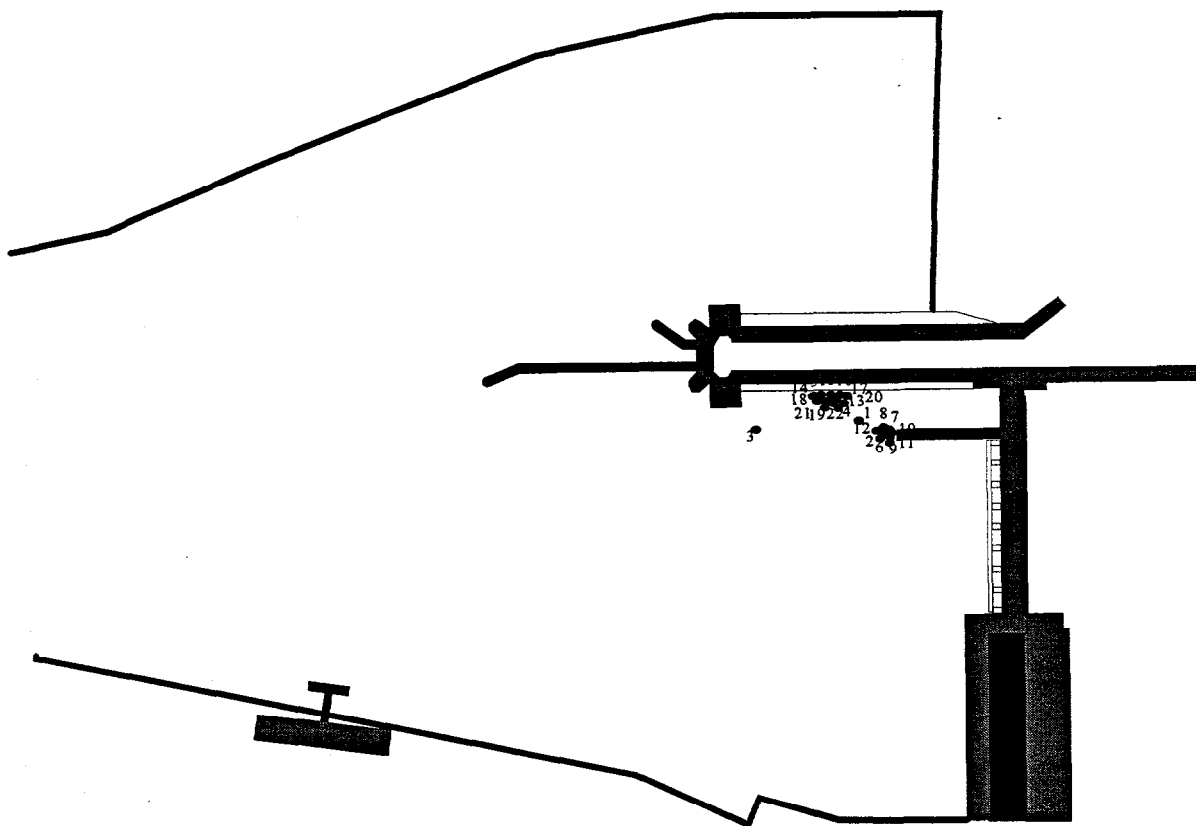|	
1 - 12:35 pm.	Lock discharge - 10:12 pm.
2 - 1:44 pm.	Lock discharge - 11:30 pm.
3 - 2:36 pm.	10 - 12:05 am.
4 - 3:51 pm.	II- 1:12 am.
5- 5:04 pm.	12 - 2:16 am.
Lock discharge - 5:20 pm.	13 - 3:13 am.
6 - 6:10 pm.	14 - 4:27 am.
7 - 7:16 pm.	15 - 6:25 am.
Sunset - 7:31 pm.	Sunrise - 6:44 am.
8 - 8:15 pm.	16 - 10:31 am.
9 - 9:19 pm.	17 - 11:37 am.

Appendix B, figure 24. Movements of northern squawfish 35-76 in the tailrace of Lower Granite Dam on July 19, 1993.

<u>Location Times</u>

1 - 11:42 am.   Lock discharge - 10: 12 pm.

Lock discharge - 12:01 pm.   IO - 10:51 pm.

2 - 12:42 pm.   Lock discharge - 11:30 pm.

3 - 1:50 pm.   11 - 12:12 am.

4 - 2:46 pm.   12 - 1:20 am.

5 - 3:55 pm.   13 - 2:20 am.

6 - 5:08 pm.   14 - 3:16 am.

Lock discharge - 5:20 pm.   15 - 4:30 am.

7 - 6:19 pm.   16 - 6:30 am.

Sunset - 7:31 pm.   Sunrise - 6:44 am.

8 - 7:37 pm.   17 - 10:37 am.

9 - 8:17 pm.

Appendix B, figure 25. Movements of northern squawfish 27-78 in the tailrace of Lower Granite Dam on July 19, 1993.
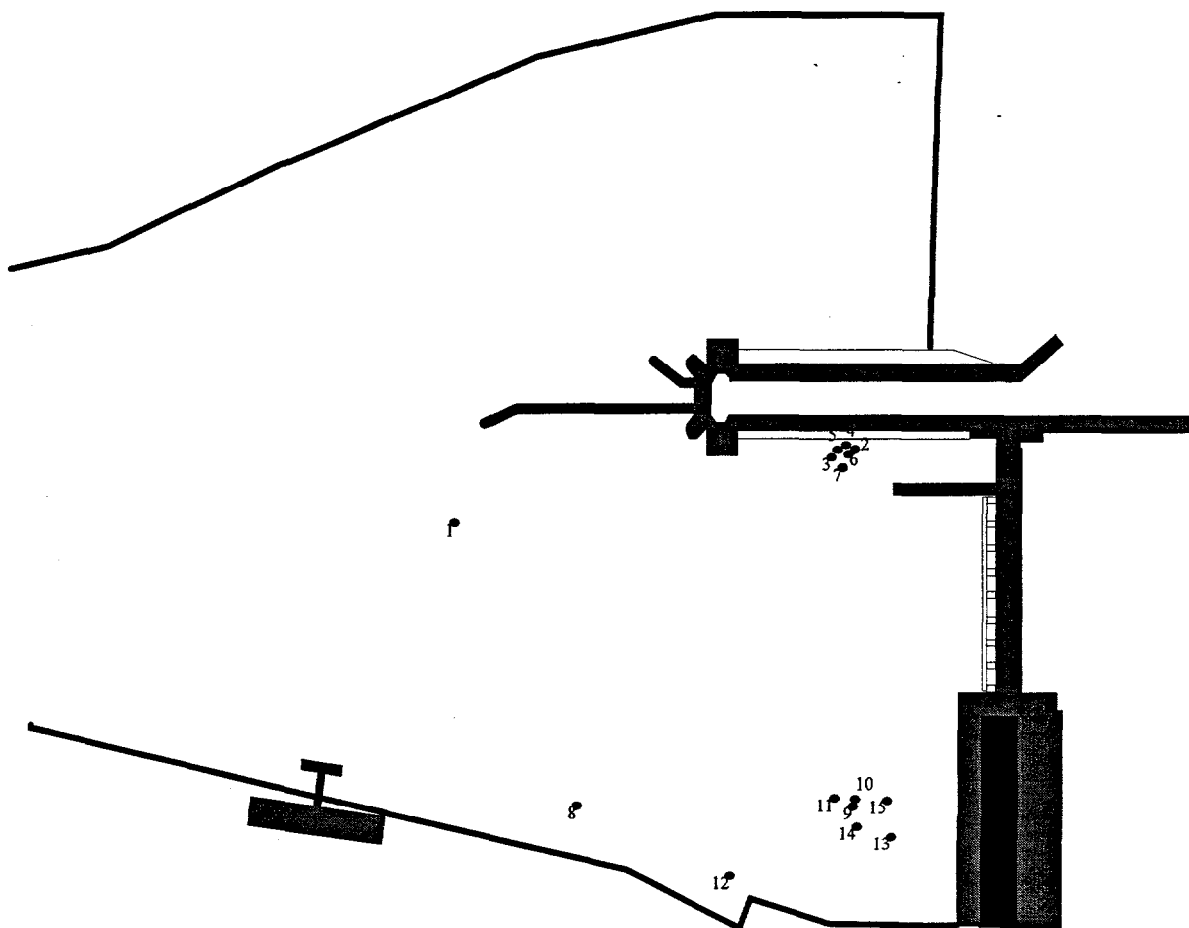
|	
1 - 12:22 pm.	Lock discharge - 10: 12 pm.
2 - 12:54 pm.	Lock discharge - 11:30 pm.
3 - 1:46 pm.	9 - 1:33 am.
4 - 2:39 pm.	IO - 2:29 am.
5 - 3:53 pm.	11 - 3:37 am.
6 - 5:05 pm.	12 - 4:40 am.
Lock discharge - 5:20 pm.	13 - 5:44 am.
7 - 6:13 pm.	14 - 6:38 am.
Sunset - 7:31 pm.	Sunrise - 6:44 am.
8 - 7:31 pm.	15 - 10:51 am.

Appendix B, figure 26. Movements of northern squawfish 32-70 in the tailrace of Lower Granite Dam on July 19, 1993.

77
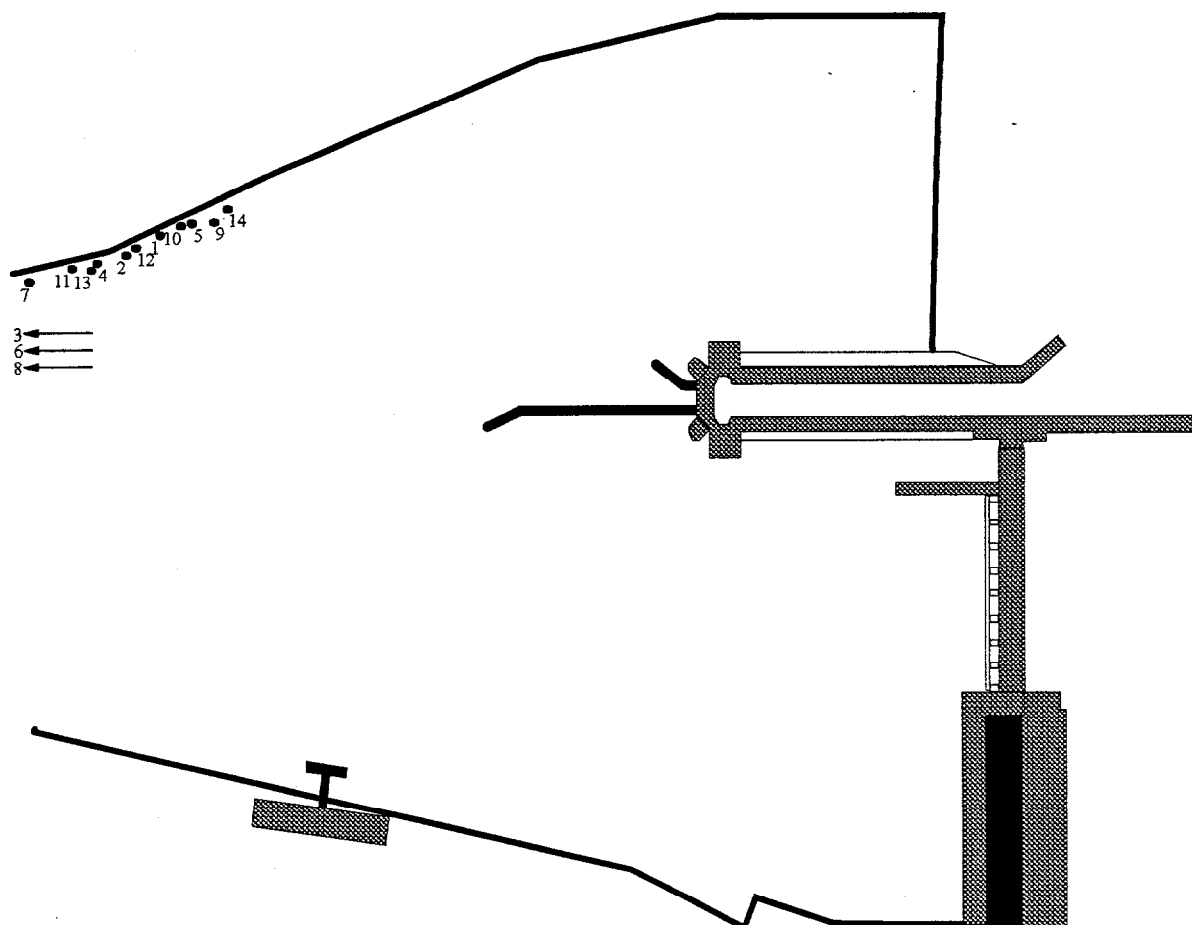
Location Times

1 - 12:15 pm.	Lock discharge - 10:12 pm.
2 - 1:00 pm.	Lock discharge - 11:30 pm.
3 - 1:59 pm.	9 - 1:40 am.
4 - 2:59 pm.	IO - 2:37 am.
5 - 4:03 pm.	11 - 3:46 am.
6 - 5:20 pm.	12 - 4:47 am.
Lock discharge - 5:20 pm.	13 - 5:52 am.
7 - 6:29 pm.	Sunrise - 6:44 am.
Sunset - 7:31 pm.	14 - 10:57 am.
8 - 7:46 pm.	

Appendix B, figure 27. Movements of northern squawfish 30-68 in the tailrace of Lower Granite Dam on July 19, 1993.

78
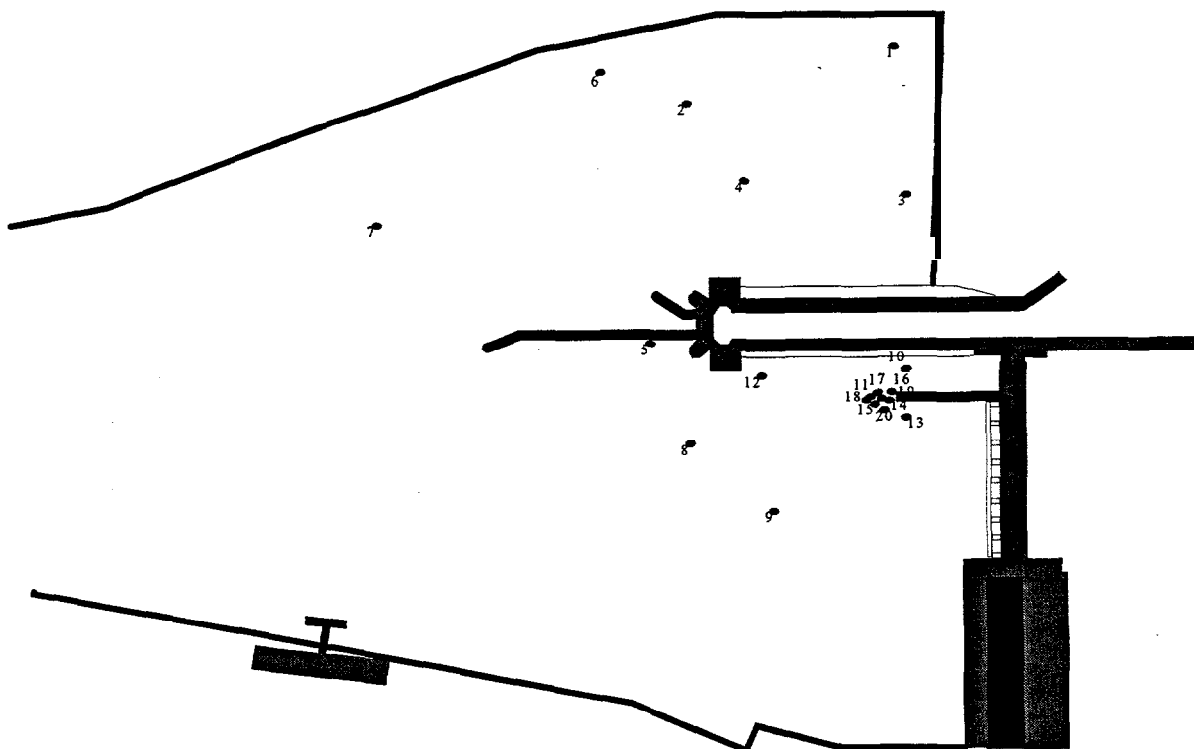
Location Times

Sunset - 7:23 pm.	13 - 12:01 pm.
1 - 7:43 pm.	Lock discharge - 12:20 pm.
2 - 10:49 pm.	Lock discharge - 12:45 pm.
3 - 12:54 am.	14 - 1:14 pm.
4 - 1:50 am.	15 - 2:11 pm.
5 - 2:46 am.	16 - 3:03 pm.
6 - 2:56 am.	Lock discharge - 3:30 pm.
7 - 4:02 am.	17 - 4:04 pm.
8 - 5:59 am.	18 - 5:00 pm.
9 - 6:46 am.	19 - 5:58 pm.
Sunrise - 6:53 am.	Lock discharge - 6:30 pm.
IO - 8:18 am.	20 - 7:08 pm.
11 - 10:09 am.	Sunset - 7:23 pm.
12 - 11:04 am.	

Appendix B, figure 28. Movements of northern squawfish 30-78 in the tailrace of Lower Granite Dam on July 27, 1993.

79
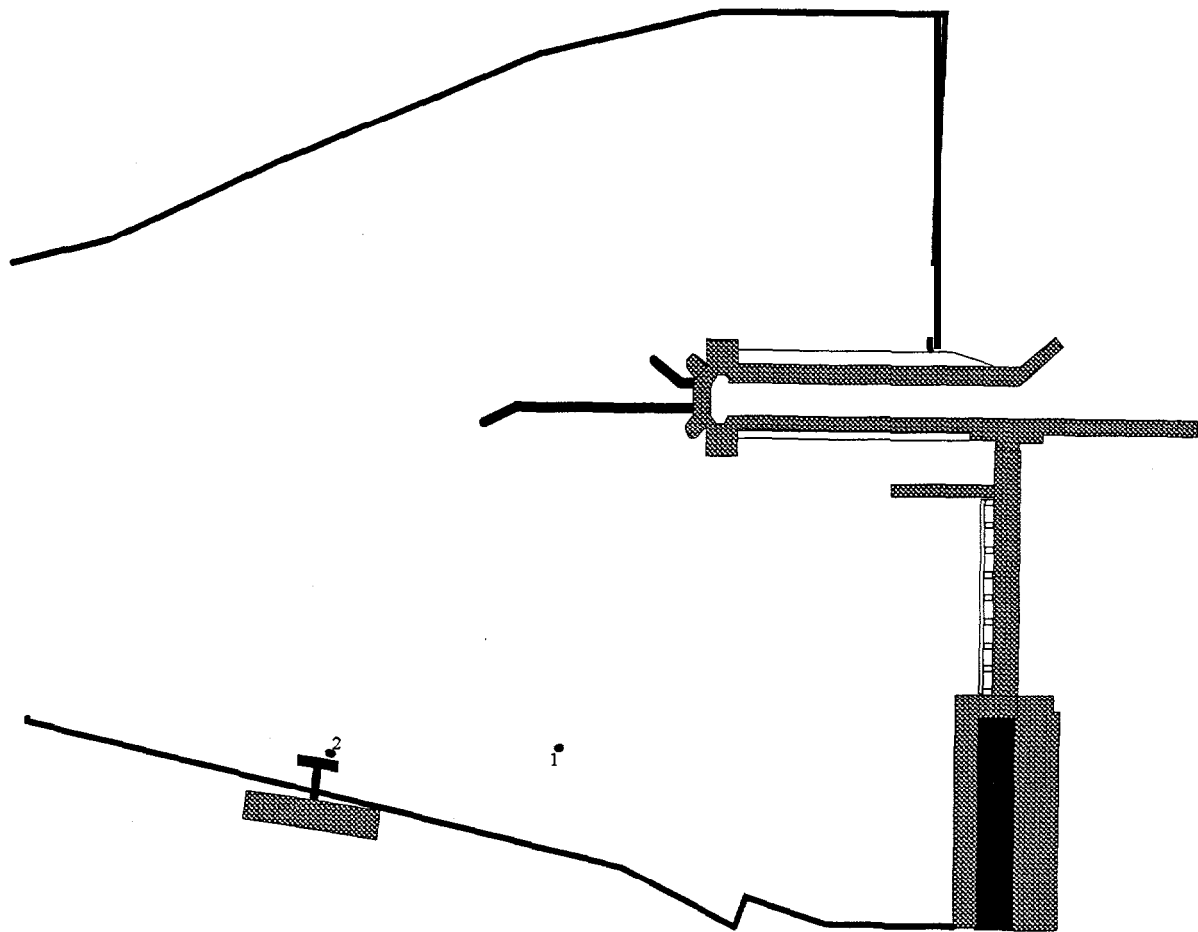
Appendix B, figure 29. Movements of northern squawfish 34-76 in the tailrace of Lower Granite Dam on July 27, 1993.
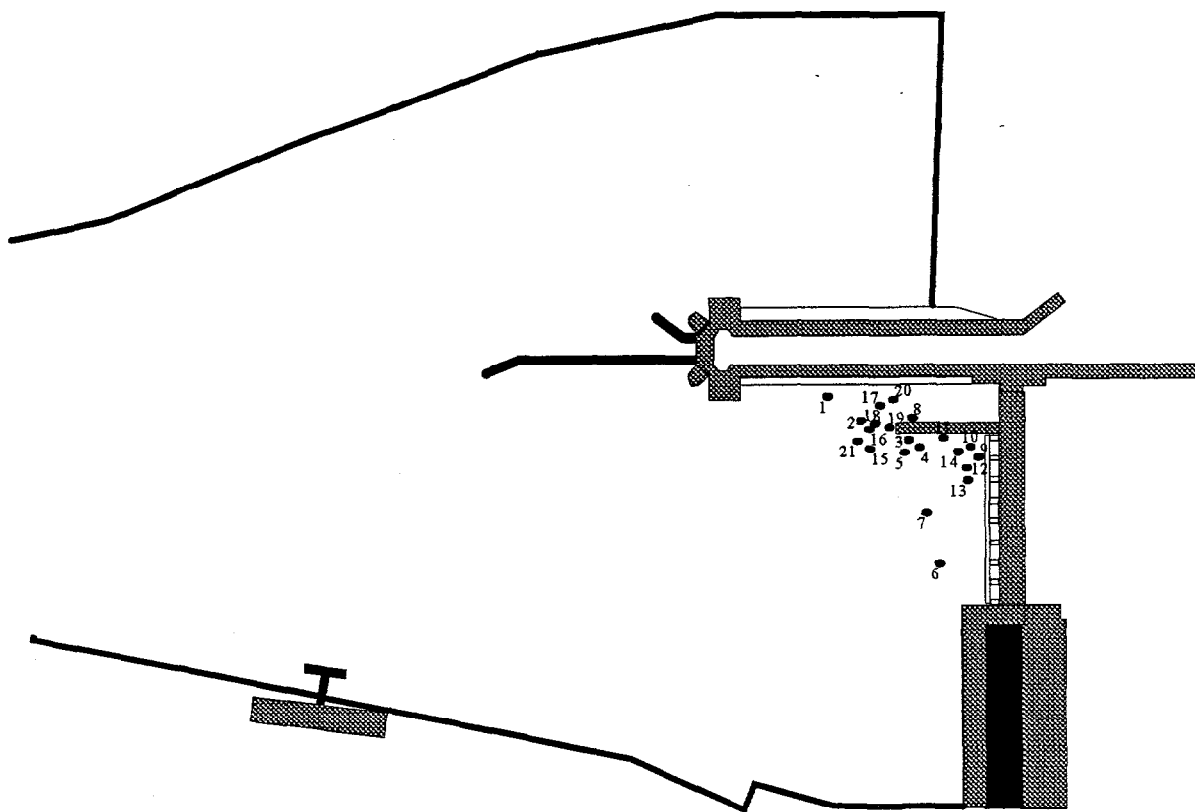
Location Times

1 - 8:33 pm.	14 - 11:09 am.
2 - 10:32 pm.	15 - 12:09 pm.
3 - 11:35 pm.	Lock discharge - 12:20 pm.
4 - 12:35 am.	Lock discharge - 12:45 pm.
5 - 1:36 am.	16 - 1:26 pm.
6 - 2:41 am.	17 - 2:22 pm.
7 - 3:40 am.	18 - 3:20 pm.
8 - 4:31 am.	Lock discharge - 3:30 pm.
9 - 5:40 am.	19 - 5:04 pm.
10 - 6:29 am.	20 - 6:01 pm.
Sunrise - 6:53 am.	Lock discharge - 6:30 pm.
11 - 7:34 am.	21 - 7:15 pm.
12 - 8:25 am.	Sunset - 7:23 pm.
13 - 10:12 am.	

Appendix B, figure 30. Movements of northern squawfish 32-76 in the tailrace of Lower Granite Dam on July 27, 1993.

81
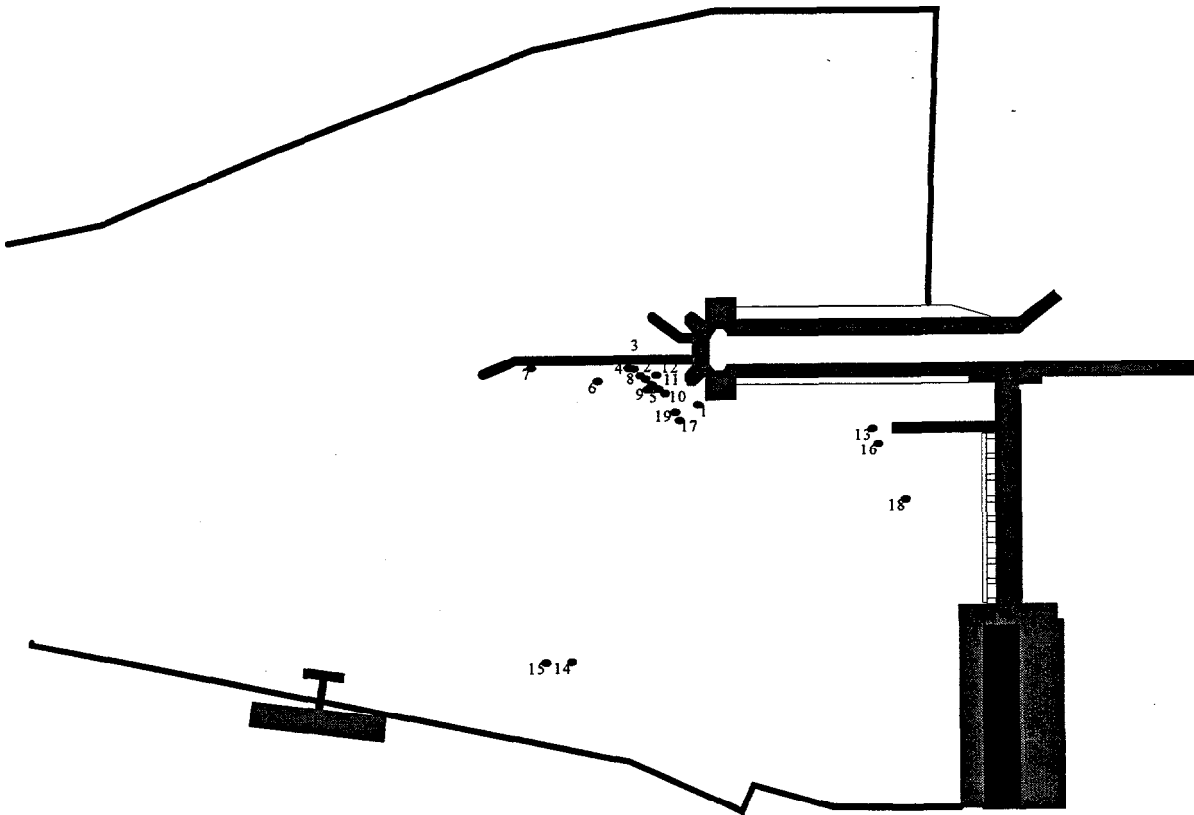
Location Times

1 - 10:38 pm.		13 - 11:18 am.	
2 - 11:46 pm.		Lock discharge - 12:20 pm.	
3 - 12:44 am.		Lock discharge - 12:45 pm.	
4 - 1:41 am.		14 - 1:41 pm.	
5 - 3:53 am.		15 - 2:34 pm.	
6 - 4:36 am.		Lock discharge - 3:30 pm.	
7 - 5:47 am.		16 - 4:02 pm.	
8 - 6:38 am.		17 - 5:12 pm.	
Sunrise - 6:53 am.		18 - 6:11 pm.	
9 - 7:42 am.		Lock discharge - 6:30 pm.	
IO - 8:34 am.		19 - 7:20 pm.	
11 - 9:28 am.		Sunset - 7:23 pm.	
12 - 10:20 am.			

Appendix B, figure 31. Movements of northern squawfish 34-68 in the tailrace of Lower Granite Dam on July 27, 1993.

<u>Location Times</u>

1 - 4:40 pm.
2 - 5:39 pm.
Lock discharge - 5:50 pm.
3 - 6:41 pm.
Sunset - 7:11 pm.
4 - 7:39 pm.
5 - 9:40 pm.
6 - 10:38 pm.

Lock discharge - 11:20 pm.
7 - 11:42 pm.
8 - 12:41 am.
9 - 1:39 am.
IO - 2:35 am.

11 - 3:34 am.

12 - 5:29 am.
13 - 6:25 am.
Sunrise - 7:04 am.

14 - 7:22 am.
15 - 8:08 am.
16 - 9:14 am.
17 - 10:14 am.
Lock discharge - 11:23 am.
18 - 11:53 am.

19 - 12:43 pm.
20 - 2:05 pm.
21 - 3:03 pm.
Lock discharge - 3:40 pm.
22 - 4:22 pm.

Appendix B, figure 32. Movements of northern squawfish 34-66 in the tailrace of Lower Granite Dam on August 5, 1993.

83
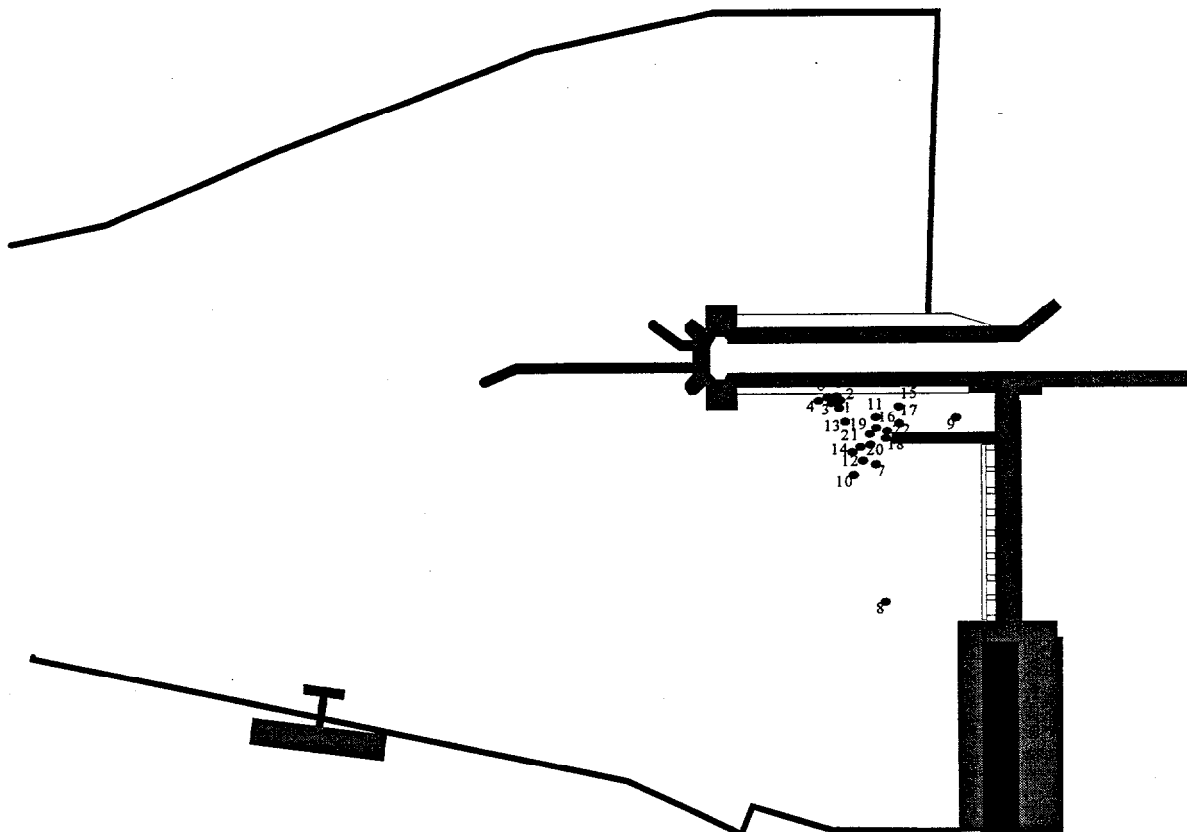
Location Times

1 - 4:43 pm.	12 - 4:34 am.
2 - 5:41 pm.	13 - 5:34 am.
Lock discharge - 5:50 pm.	14 - 6:28 am.
3 - 6:43 pm.	Sunrise - 7:04 am.
Sunset - 7:11 pm.	15 - 7:20 am.
4 - 7:40 pm.	16 - 9:16 am.
5 - 9:42 pm.	17 - 10:16 am.
6 - 10:40 pm.	Lock discharge - 11:23 am.
Lock discharge - 11:20 pm.	18 - 11:55 am.
7 - 11:47 pm.	19 - 12:45 pm.
8 - 12:50 am.	20 - 2:07 pm.
9 - 1:47 am.	21 - 3:05 pm.
IO -2:40 am.	Lock discharge - 3:40 pm.
11 - 3:40 am.	22 - 4:20 pm.

Appendix B, figure 33. Movements of northern squawfish 29-02 in the tailrace of Lower Granite Dam on August 5, 1993.

84
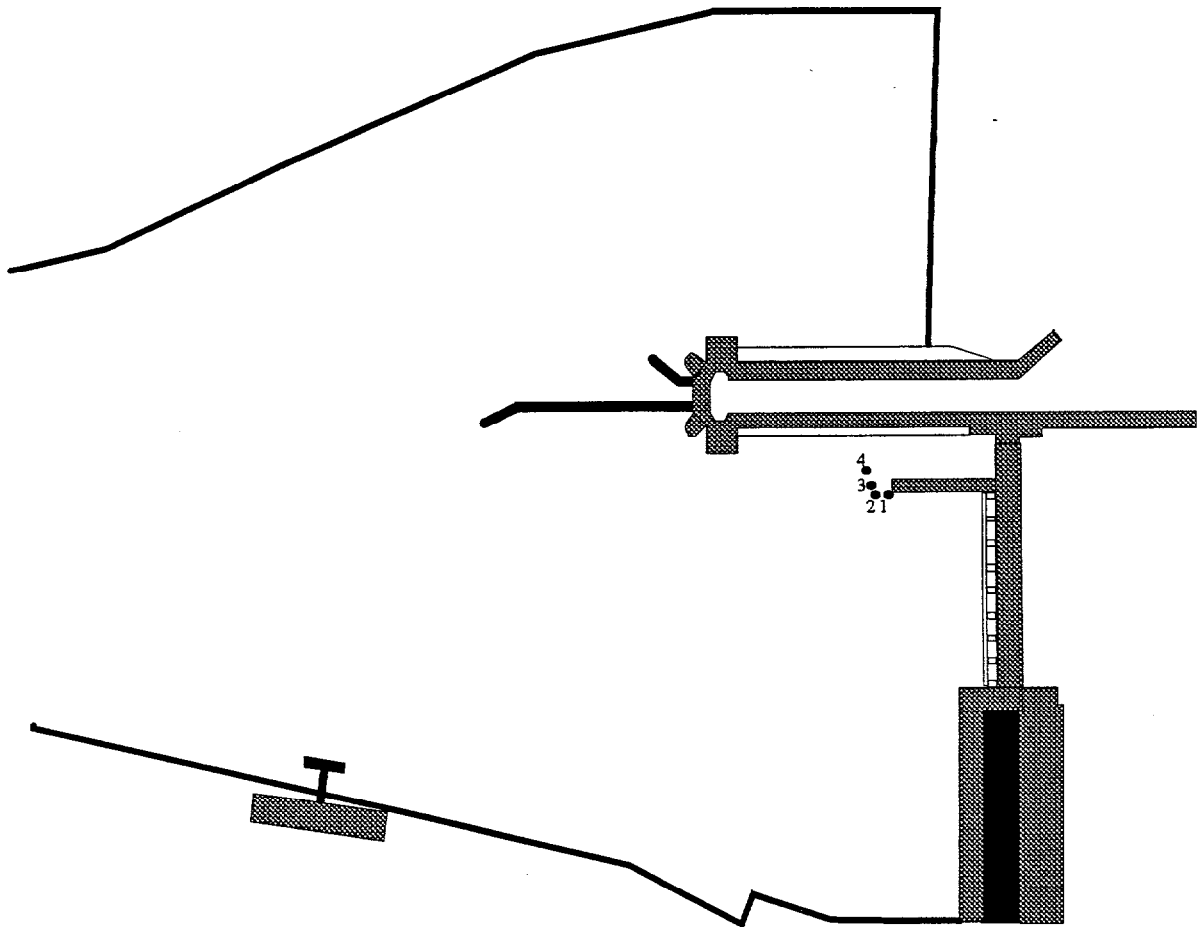
Location Times

1 - 4:49 pm.   3 - 6:45 pm.
2 - 5:45 pm.   Sunset 7:11 pm.
Lock discharge - 5:50   4 - 7:41 pm.
pm.

Appendix B, figure 34. Movements of northern squawfish 35-74 in the tailrace of Lower Granite Dam on August 5, 1993.
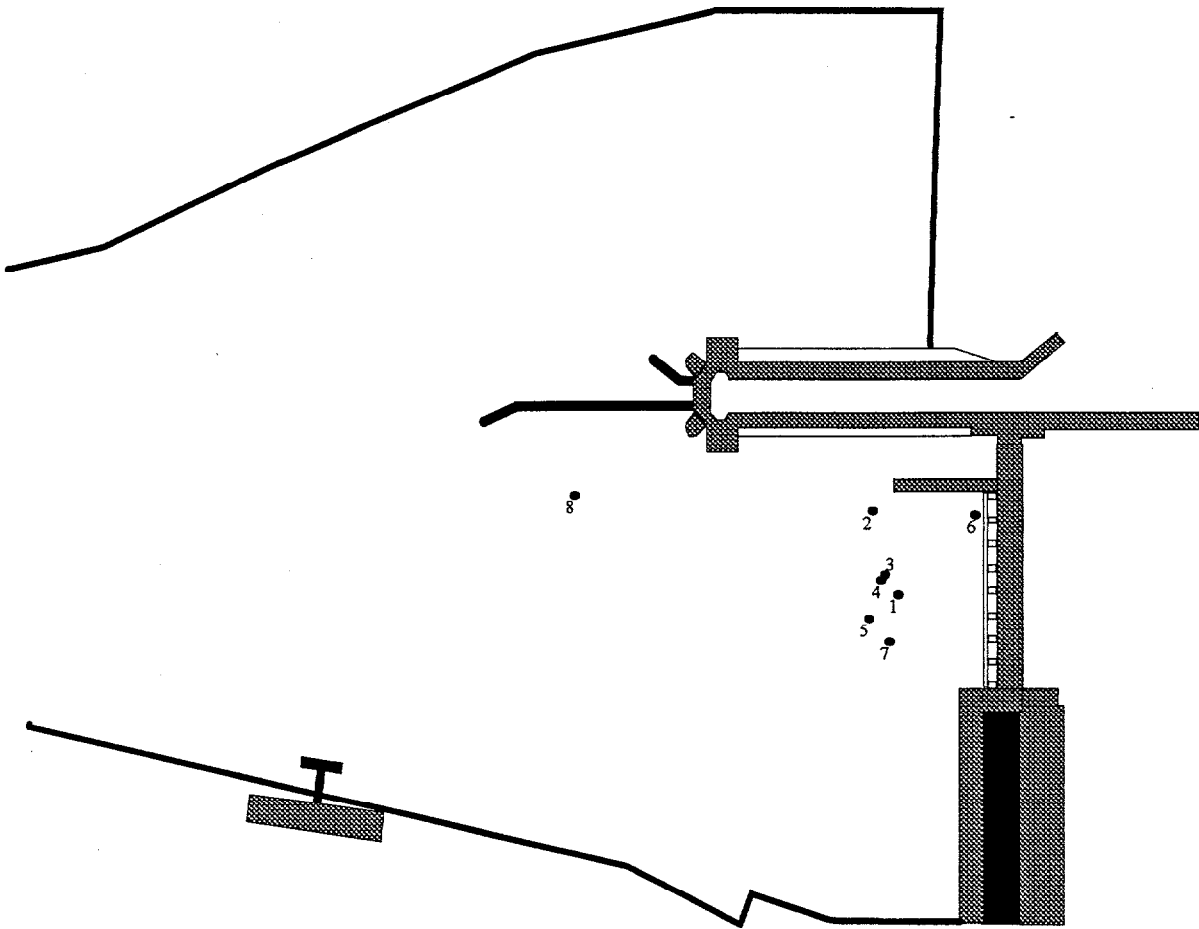
Location Times

1 - 9:47 pm.	5 - 1:51 am.
2 - 10:44 pm.	6 - 2:47 am.
Lock discharge - 11:20 pm.	7 - 3:44 am.
3 - 11:50 pm.	8 - 4:40 am.
4 - 12:53 am.	

Appendix B, figure 35. Movements of northern squawfish 31-72 in the tailrace of Lower Granite Dam on August 5, 1993.
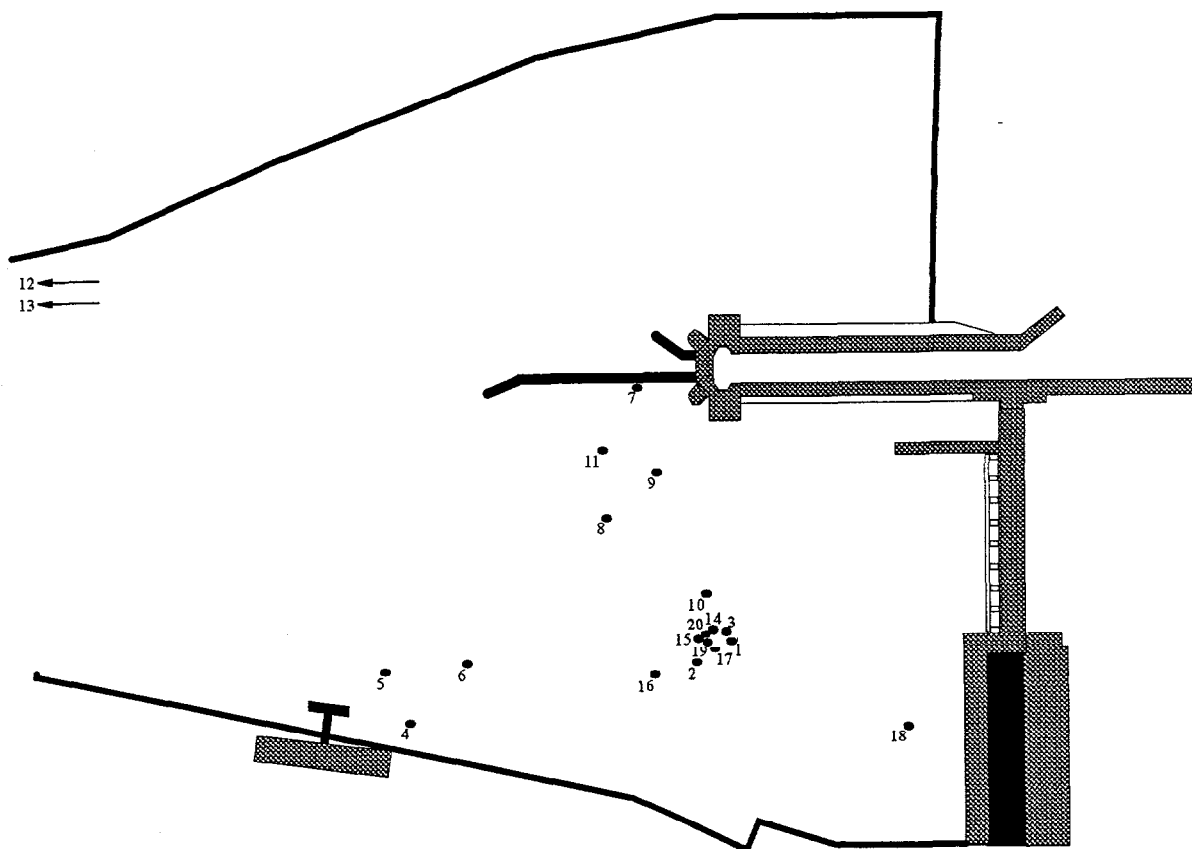
1 - 4:57 pm.	11 - 4:42 am.
Lock discharge - 5:50 pm.	12 - 6:13 am.
2 - 6:17 pm.	Sunrise - 7:04 am.
Sunset - 7:11 pm.	13 - 7:12 am.
3 - 7:11 pm.	14 - 9:08 am.
4 - 9:54 pm.	15 - 10:08 am.
5 - 10:51 pm.	Lock discharge - 11:23 am.
Lock discharge - 11:20 pm.	16 - 11:43 am.
6 - 11:54 pm.	17 - 12:37 pm.
7 - 12:59 am.	18 - 1:58 pm.
8 - 1:56 am.	19 - 2:57 pm.
9 - 2:51 am.	Lock discharge - 3:40 pm.
IO - 3:48 am.	20 - 4:13 pm.

Appendix B, figure 36. Movements of northern squawfish 34-64 in the tailrace of Lower Granite Dam on August 5, 1993.

Location Times

1 - 4:54 pm. 2 - 5:53 pm.
Lock discharge - 5:50
pm.

Appendix B, figure 37. Movements of northern squawfish 30-72 in the tailrace of Lower Granite Dam on August 5, 1993.

Location Times

Sunset - 7:11 pm.
1 - 7:15 pm.
2 - 9:16 pm.
3 - 9:59 pm.

Lock discharge - 11:20 pm.
4 - 1:03 am.
5 - 2:06 am.
6 - 3:10 am.
7 - 4:06 am.

8 - 6:20 am.
Sunrise - 7:04 am.

9 - 7:28 am.
IO - 9:11 am.
11 - 10:11 am.
Lock discharge - 11:23 am.
12 - 11:46 am.

13 - 12:41 pm.
14 - 2:03 pm.
15 - 3:00 pm.
Lock discharge - 3:40 pm.
16 - 4:20 pm.

Appendix B, figure 38. Movements of northern squawfish 29-70 in the tailrace of Lower Granite Dam on August 5, 1993.'
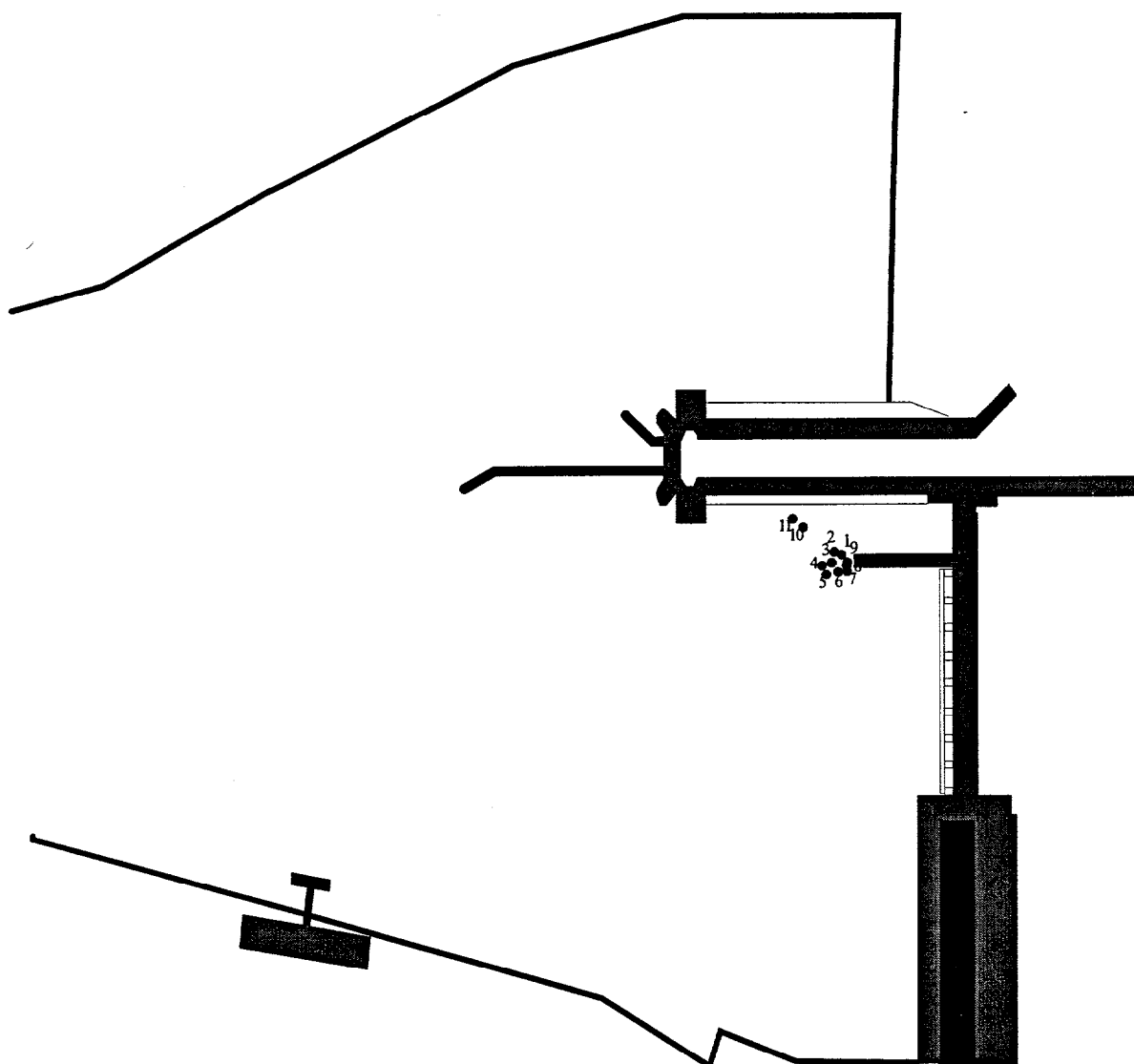
89

Appendix B, figure 39. Movements of northern squawfish 28-76 in the tailrace of Lower Granite Dam on August 5, 1993.

Appendix C
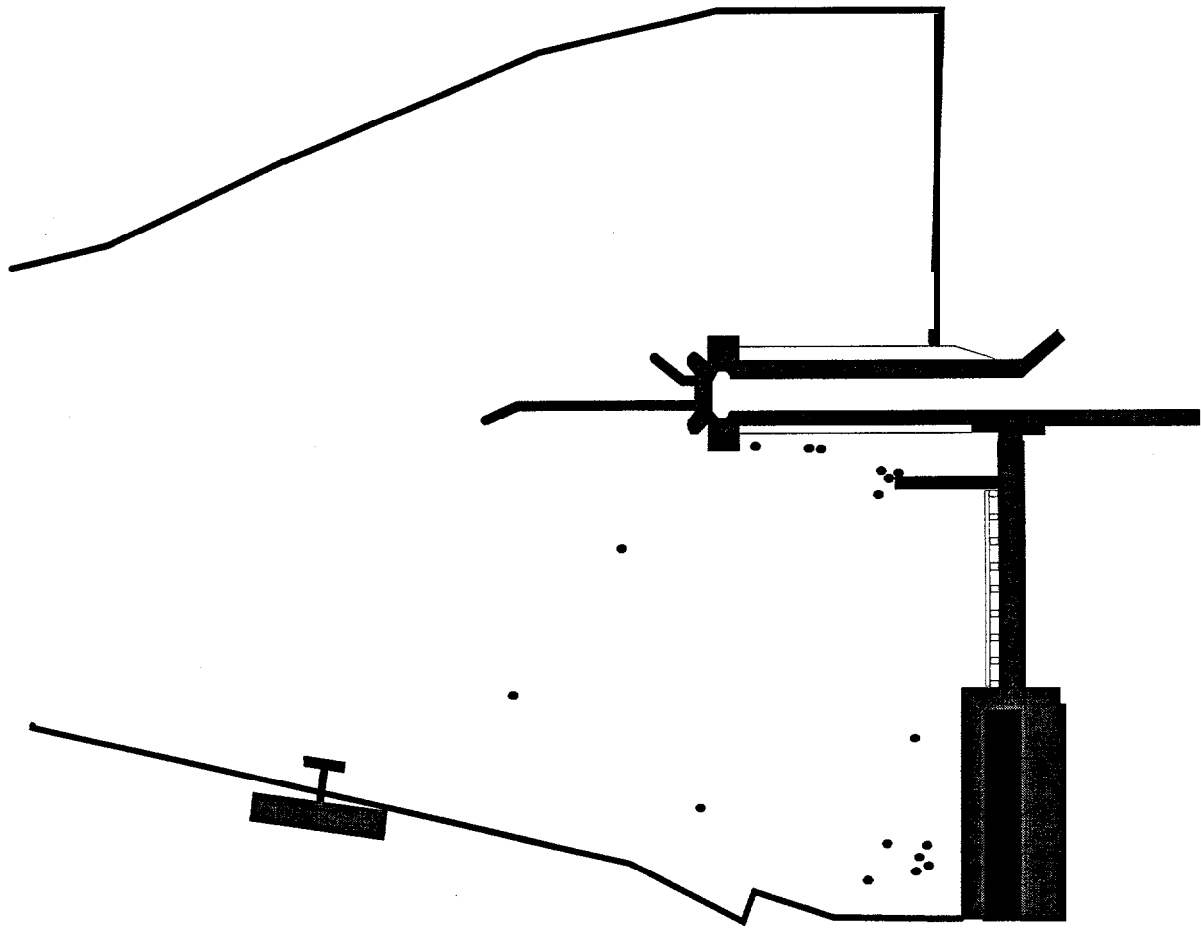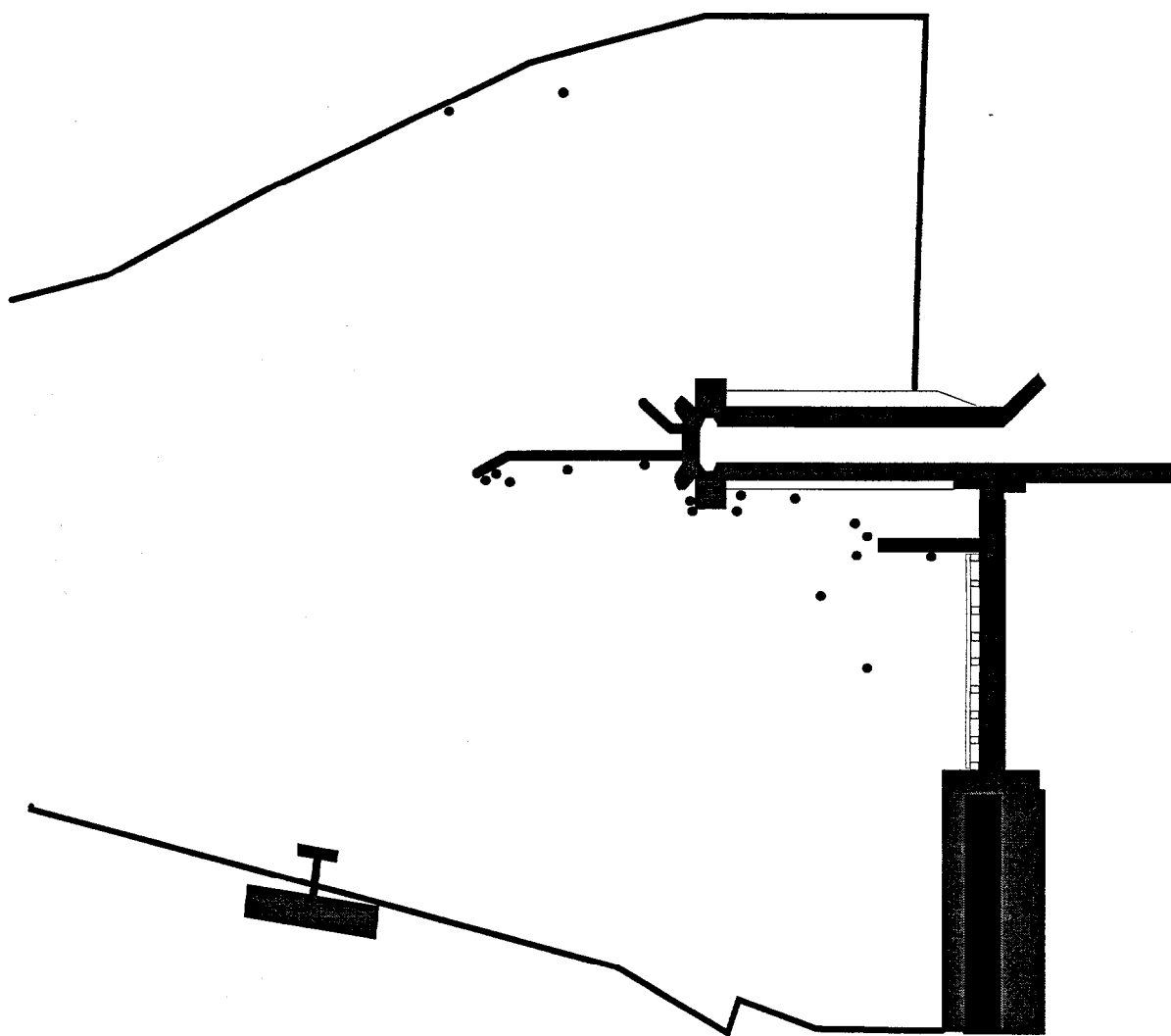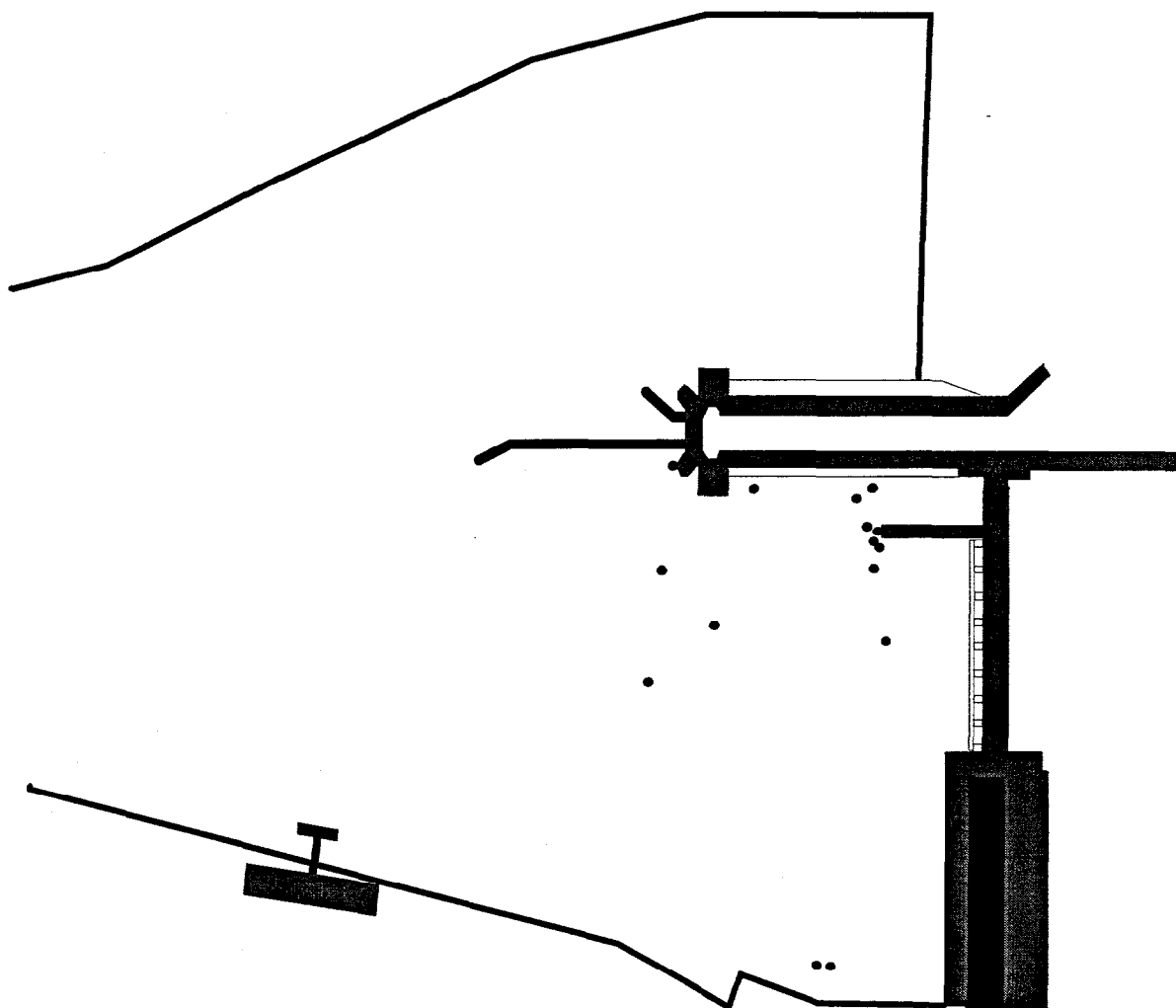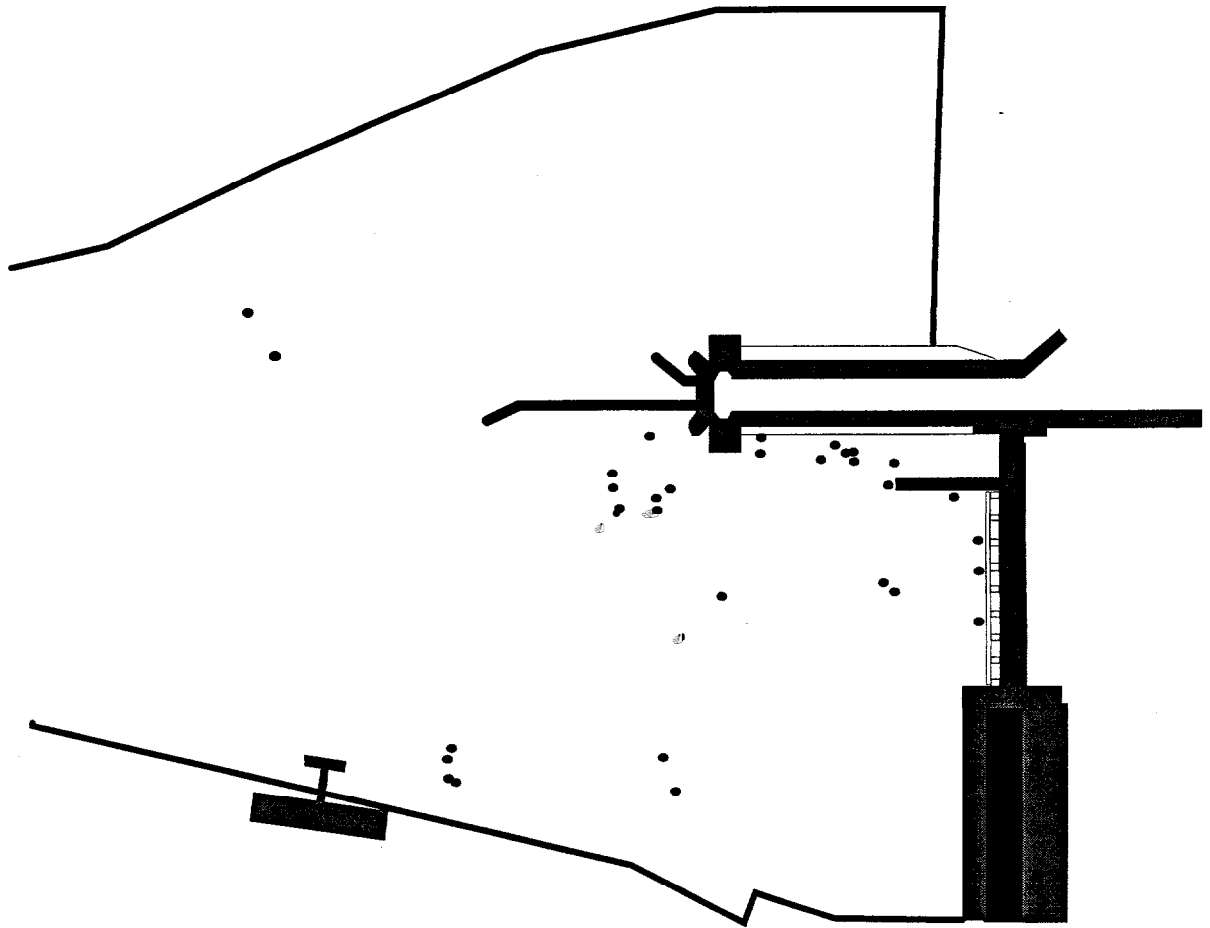

Appendix C, figure 1. Observations of northern squawfish 35-72 in the tailrace of Lower Granite Dam during the postspill period in 1993.
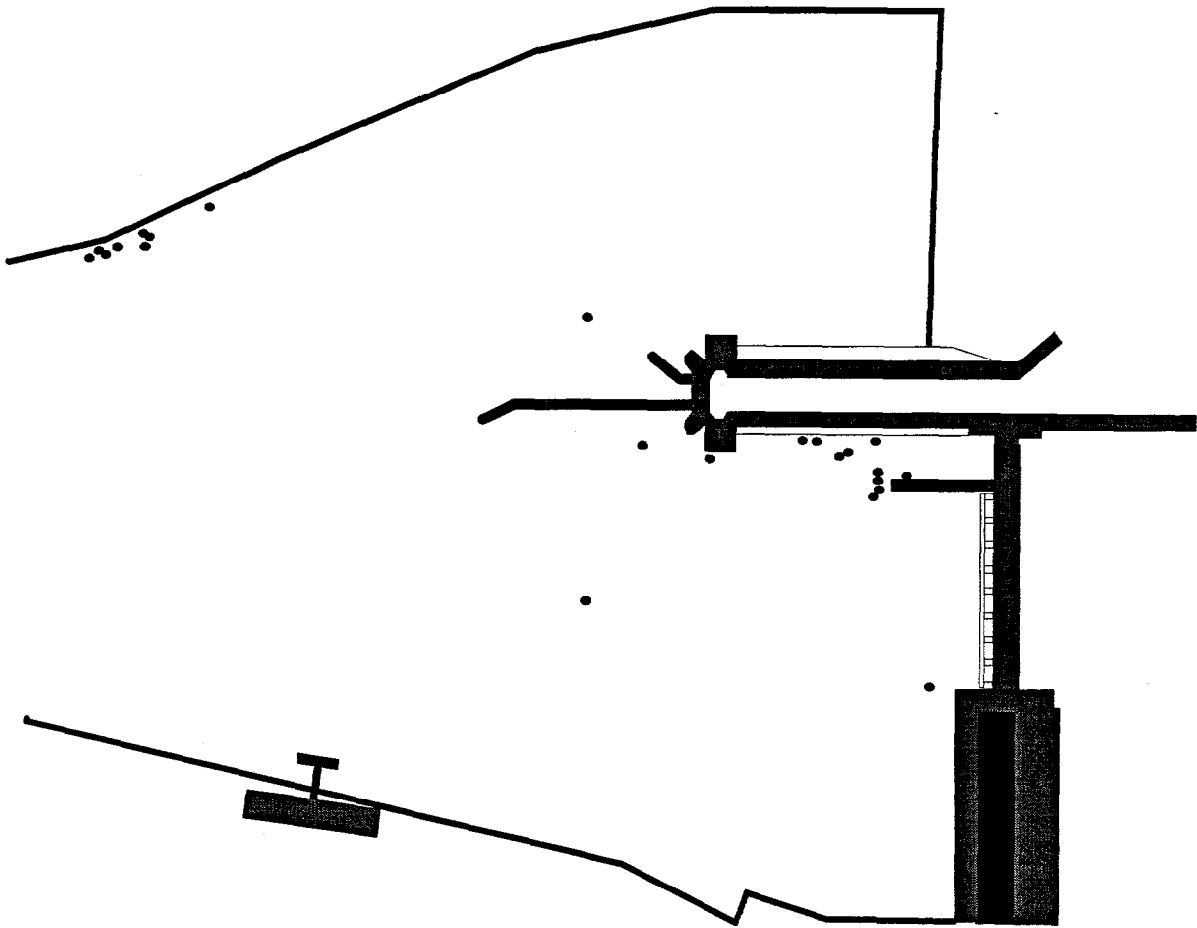
Appendix C, figure 2. Observations of northern squawfish 30-68 in the tailrace of Lower Granite Darn during the postspill period in 1993.
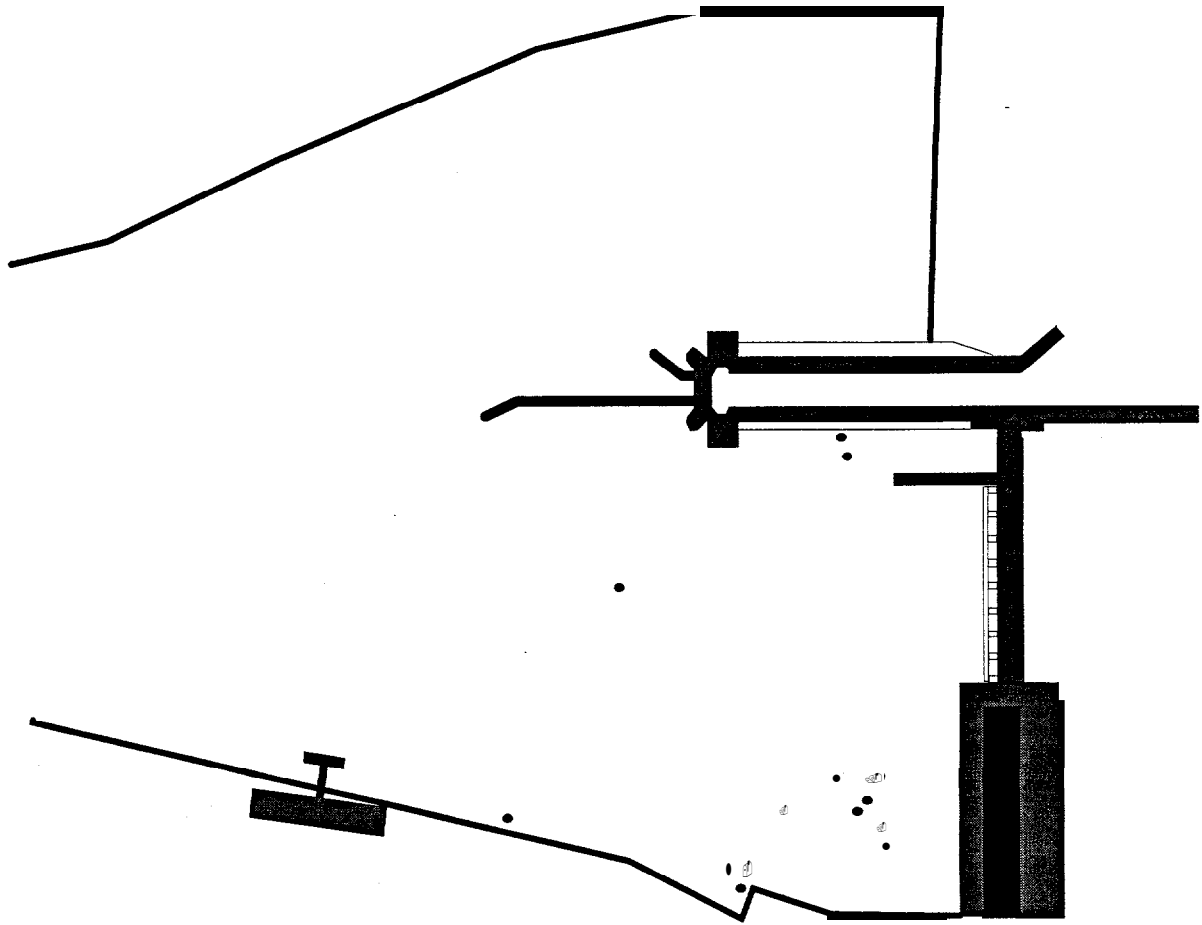
Appendix C, figure 3. Observations of northern squawfish 32-70 in the tailrace of Lower Granite Darn during the postspill period in 1993.
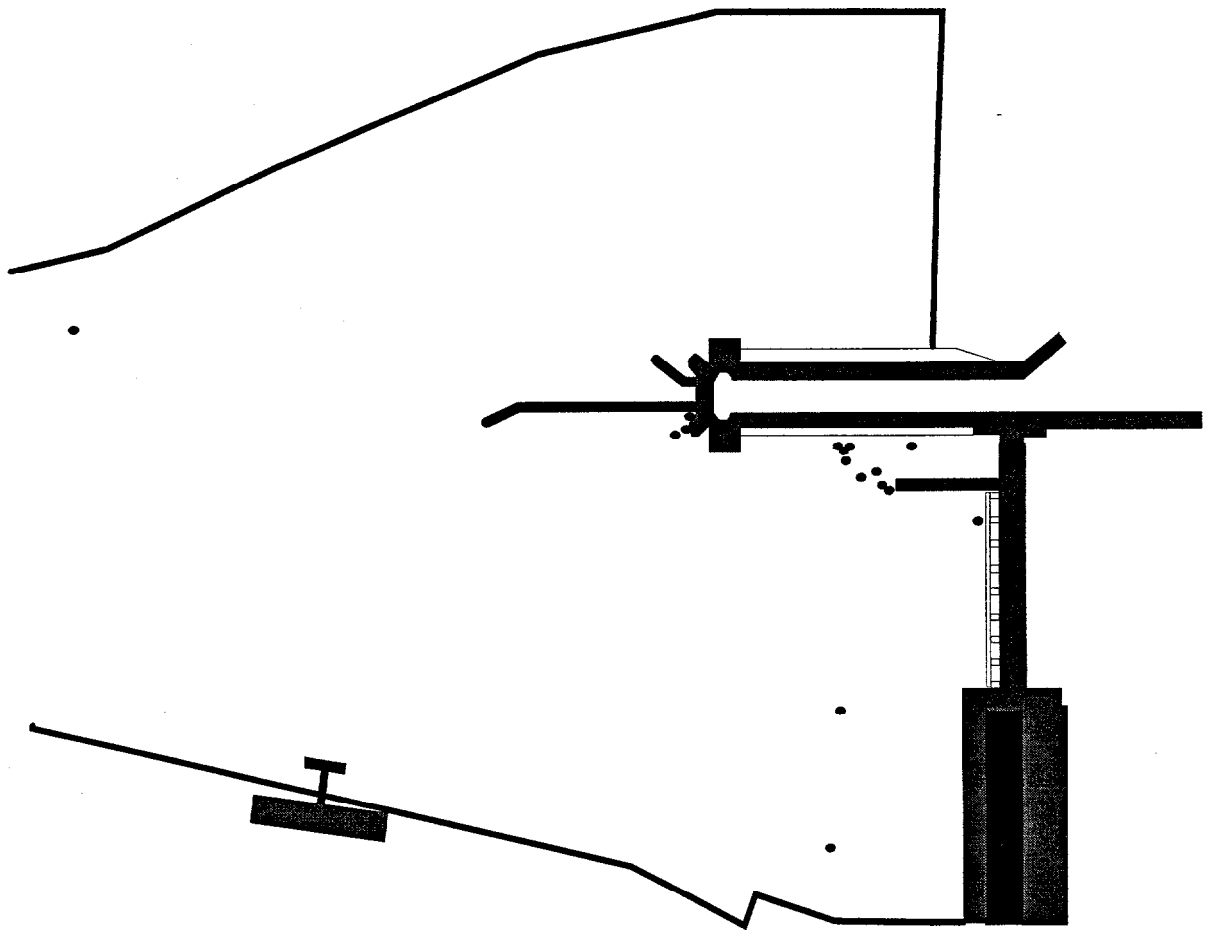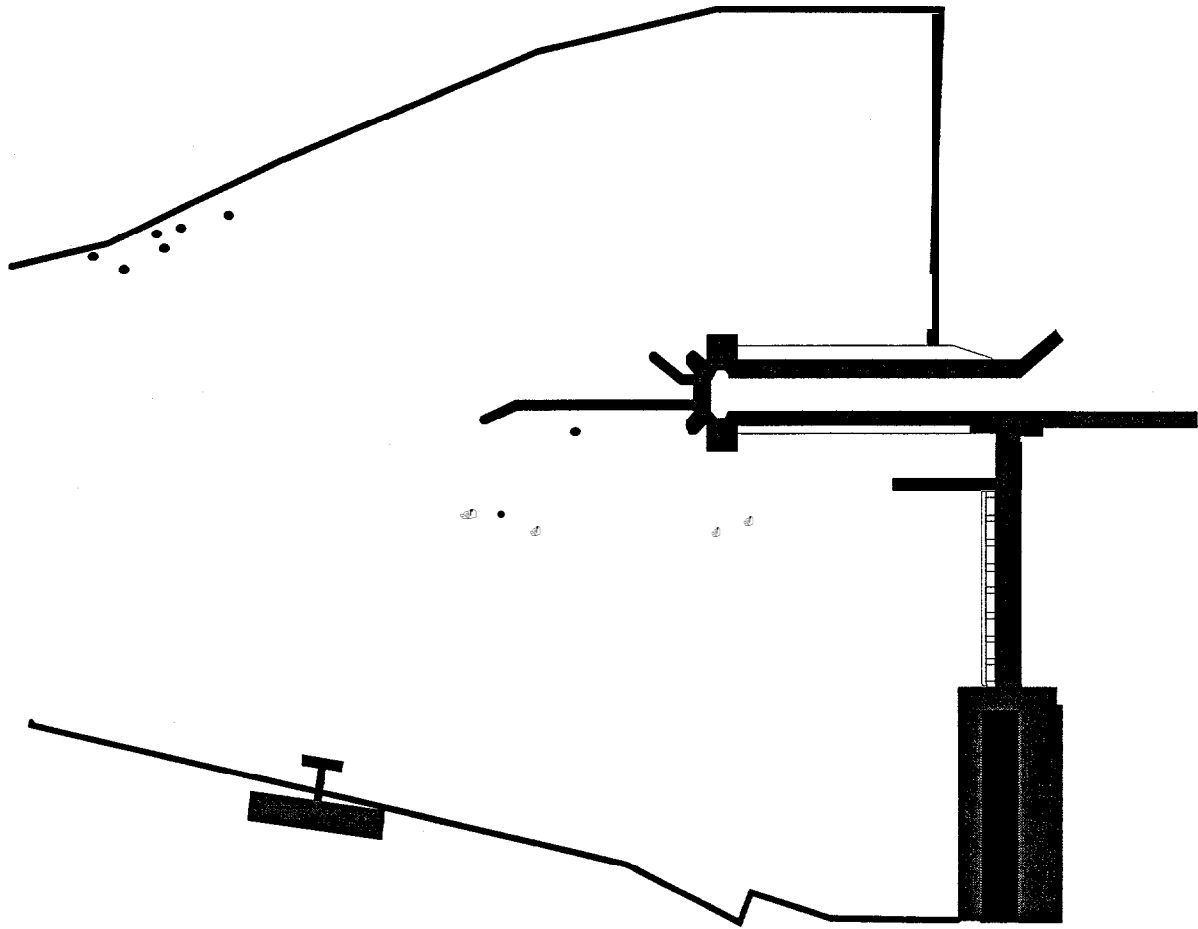
Appendix C, figure 4. Observations of northern squawfish 34-66 in the tailrace of Lower Granite Dam during the postspill period in 1993.
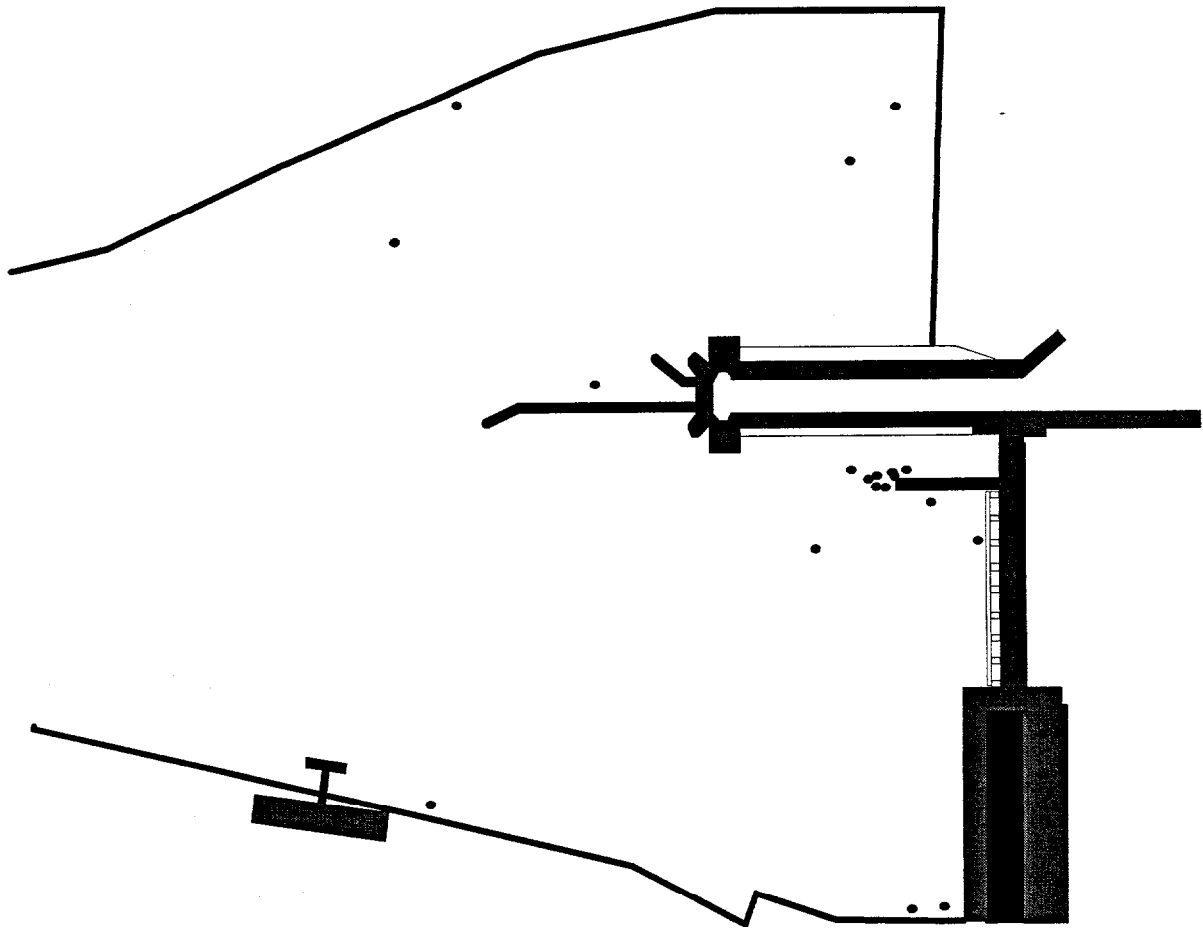
Appendix C, figure 5. Observations of northern squawfish 30-78 in the tailrace of Lower Granite Dam during the postspill period in 1993.
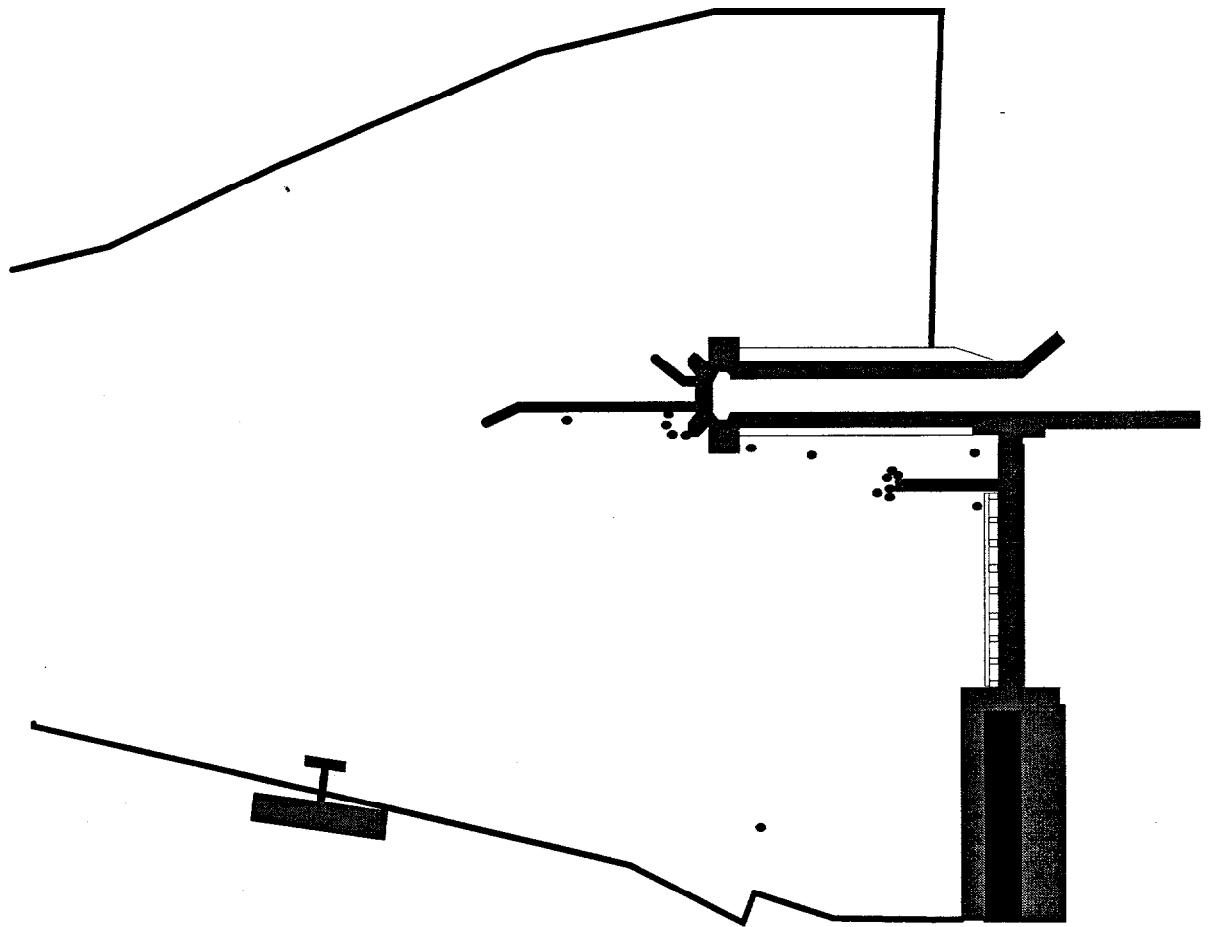
Appendix C, figure 6. Observations of northern squawfish 34-68 in the tailrace of Lower Granite Darn during the postspill period in 1993.
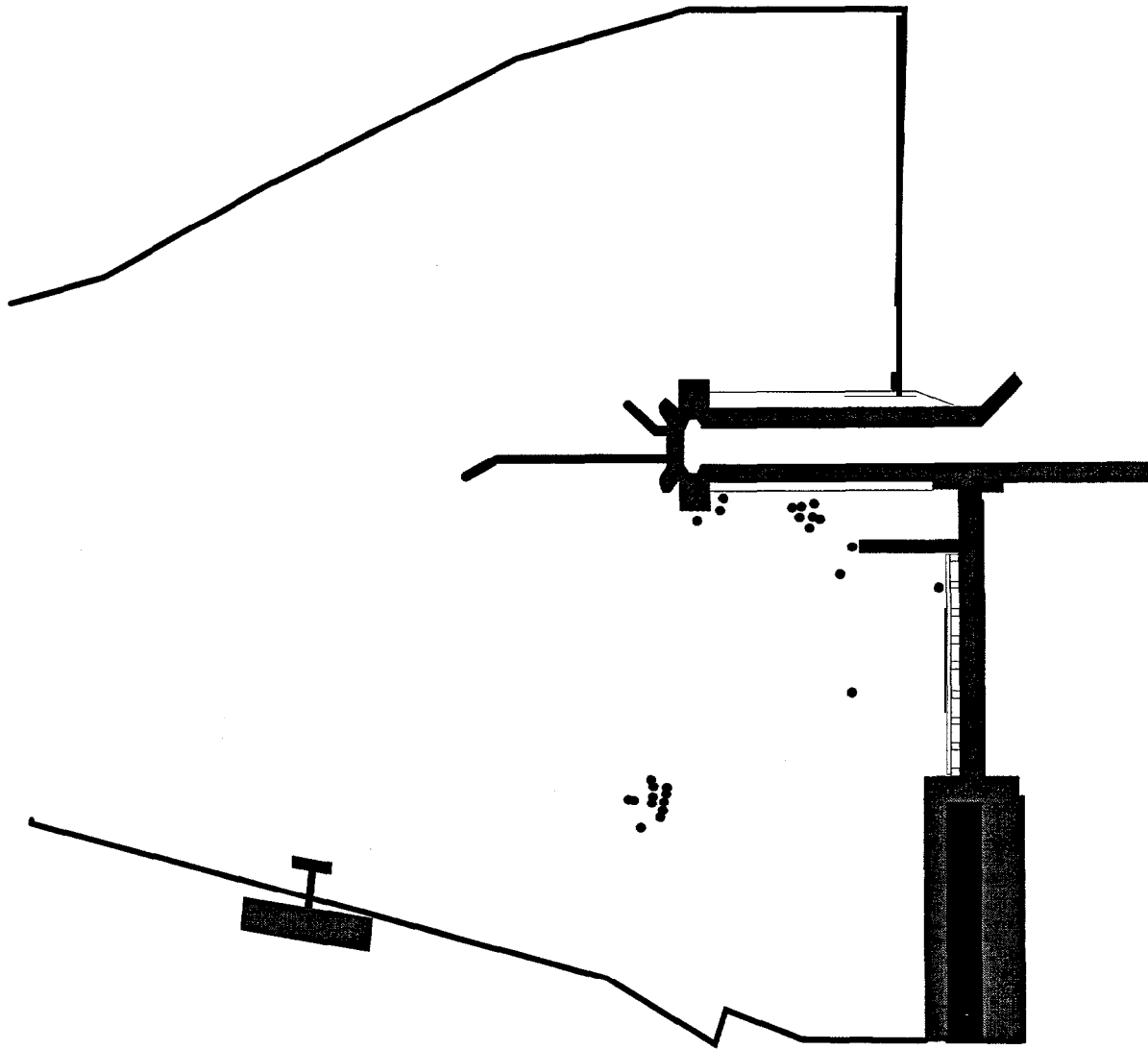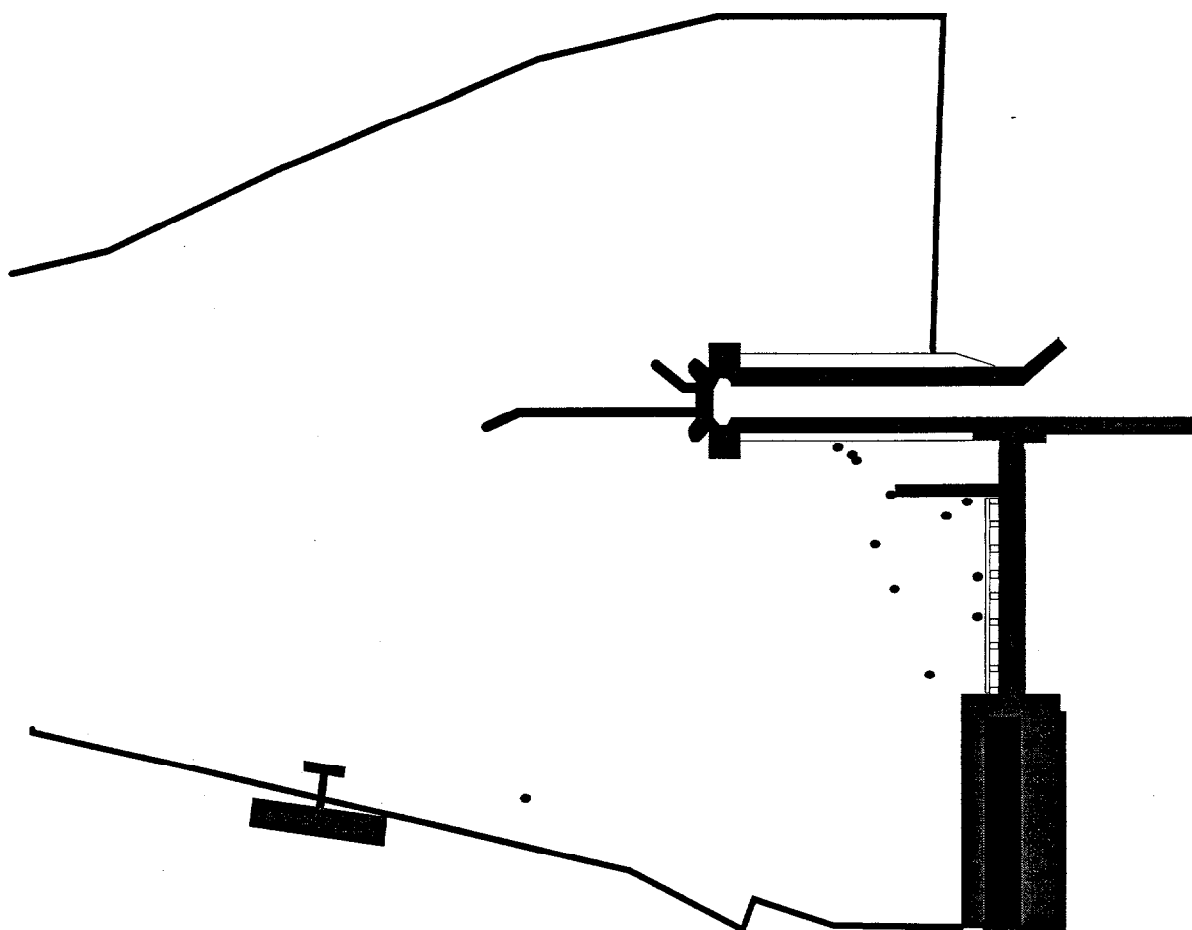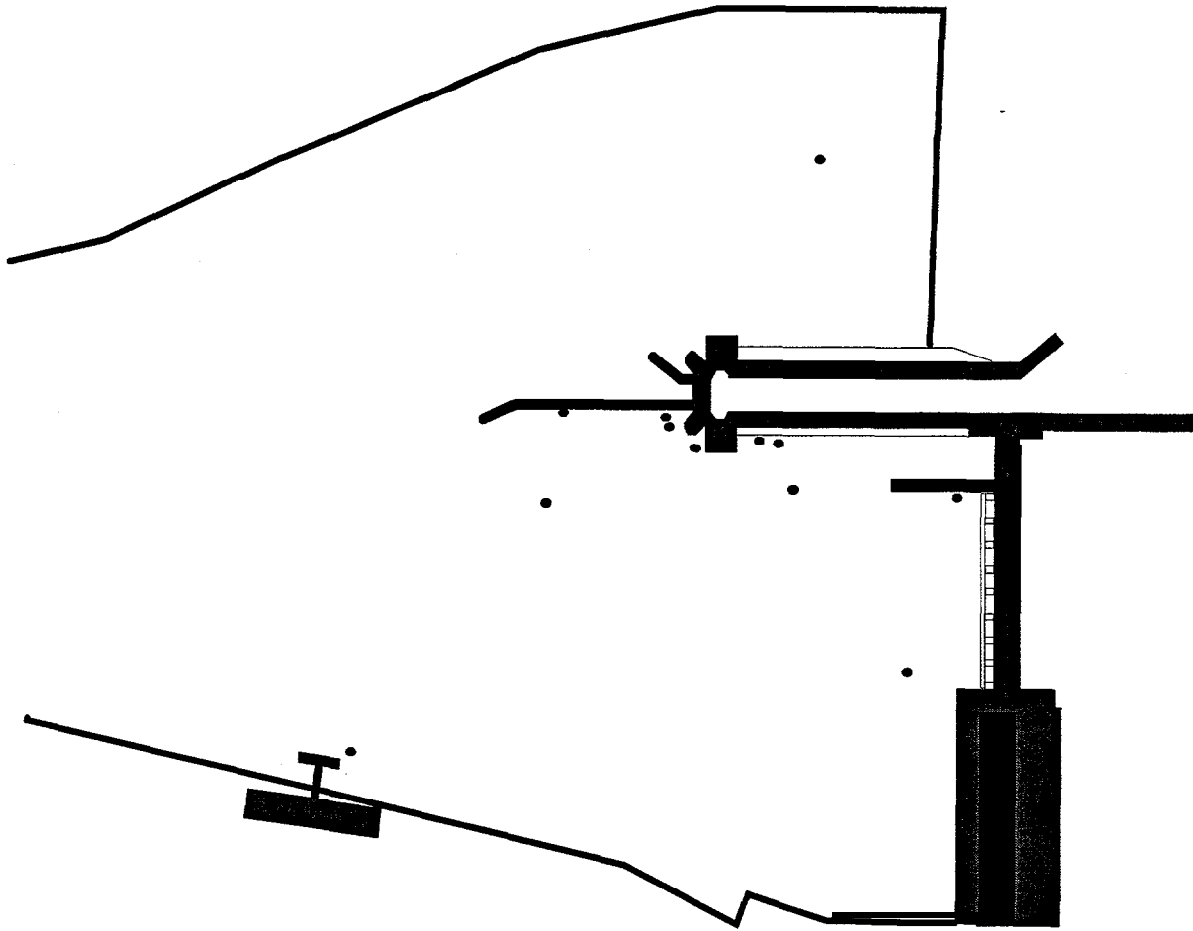
Appendix C, figure 7. Observations of northern squawfish 3 1-74 in the tailrace of Lower Granite Dam during the postspill period in 1993.
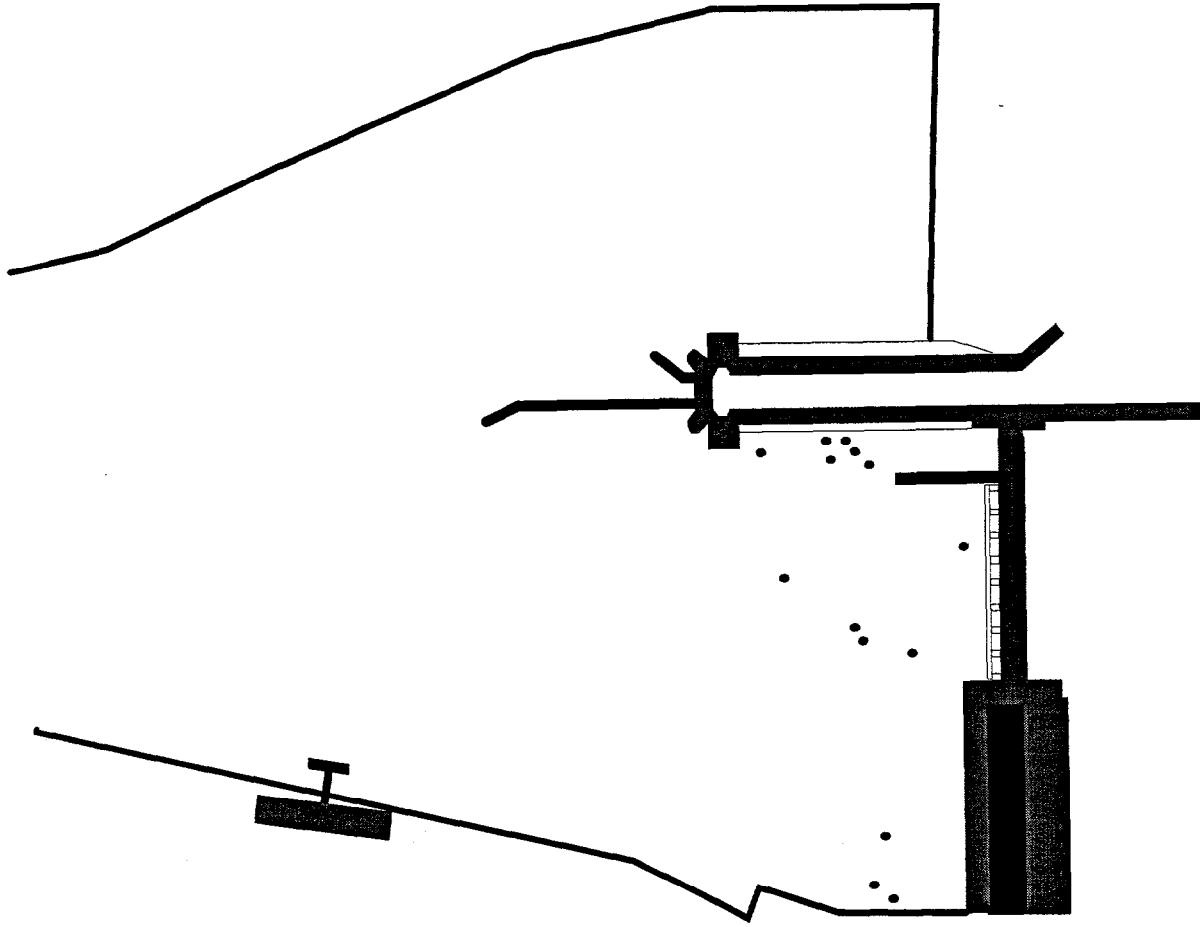
Appendix C, figure 8. Observations of northern squawfish 34-74 in the tailrace of Lower Granite Dam during the postspill period in 1993.
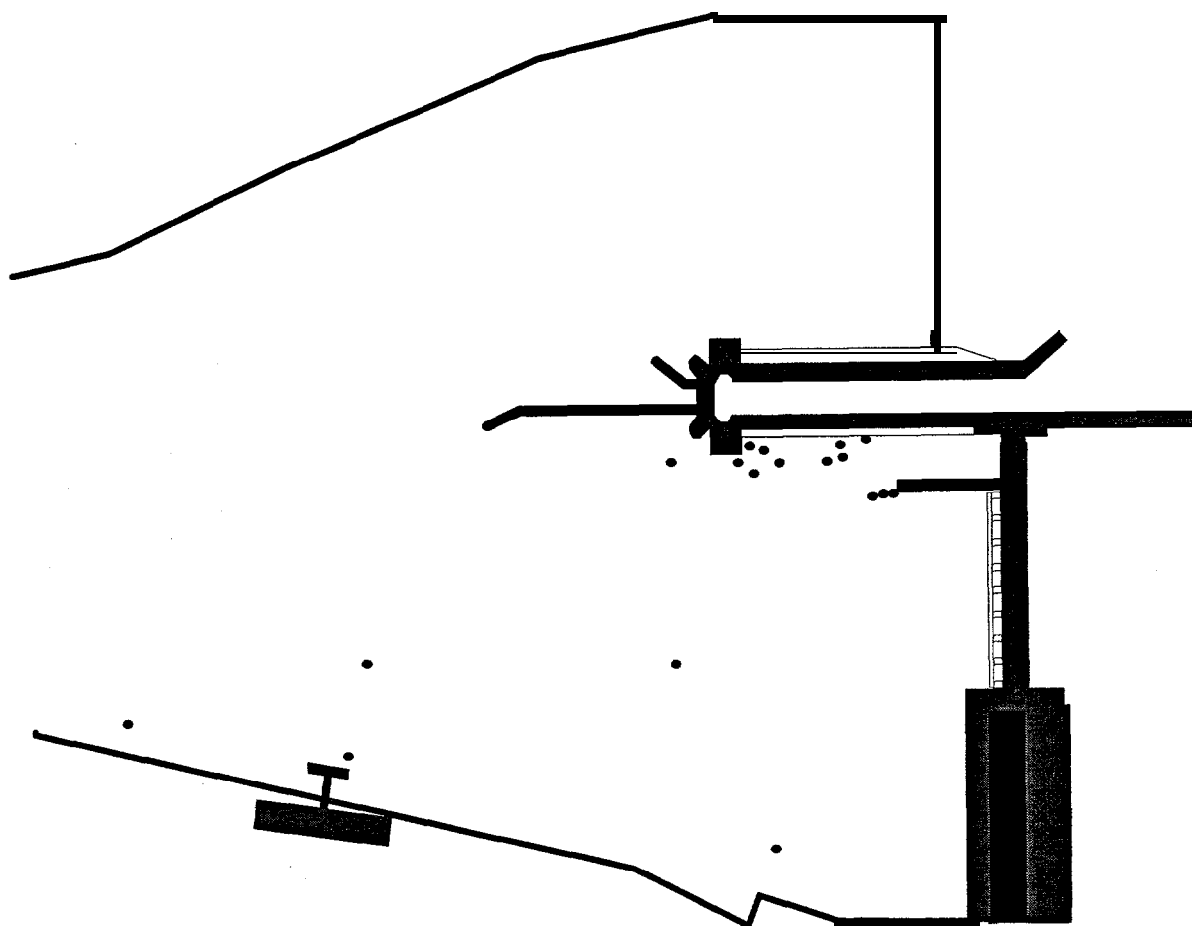
Appendix C, figure 9. Observations of northern squawfish 28-76 in the tailrace of Lower Granite Dam during the postspill period in 1993.
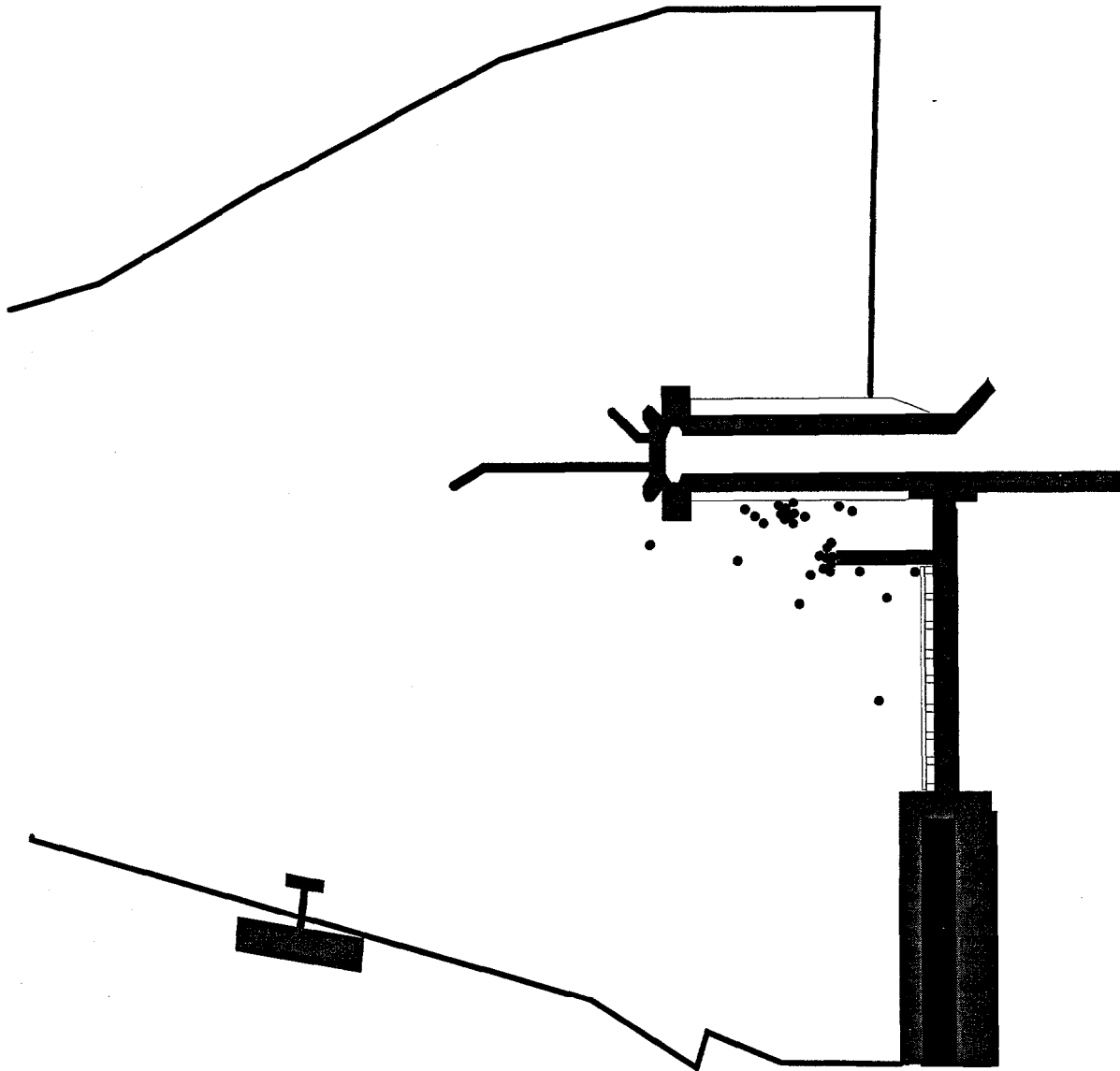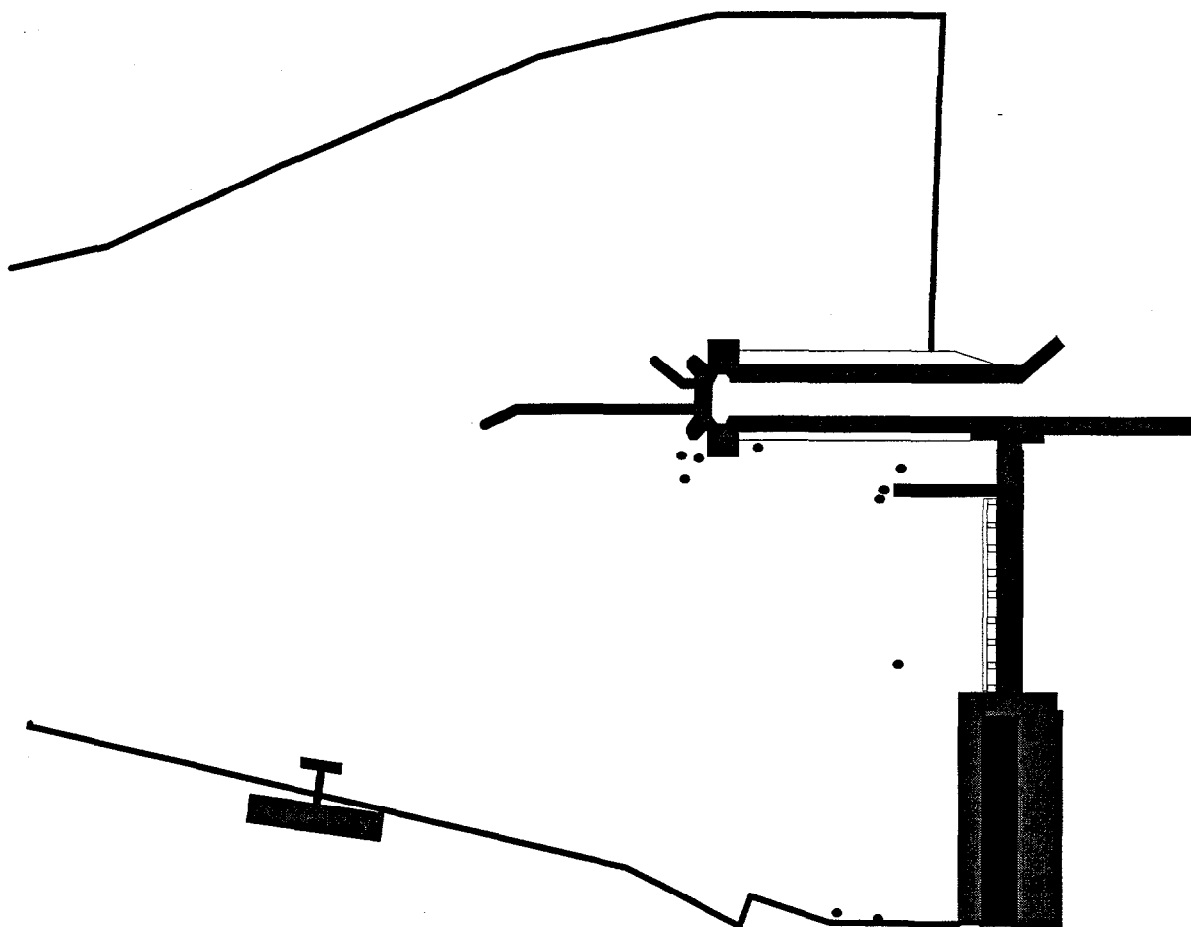
Appendix C, figure 10. Observations of northern squawfish 29-02 in the tailrace of Lower Granite Darn during the postspill period in 1993.
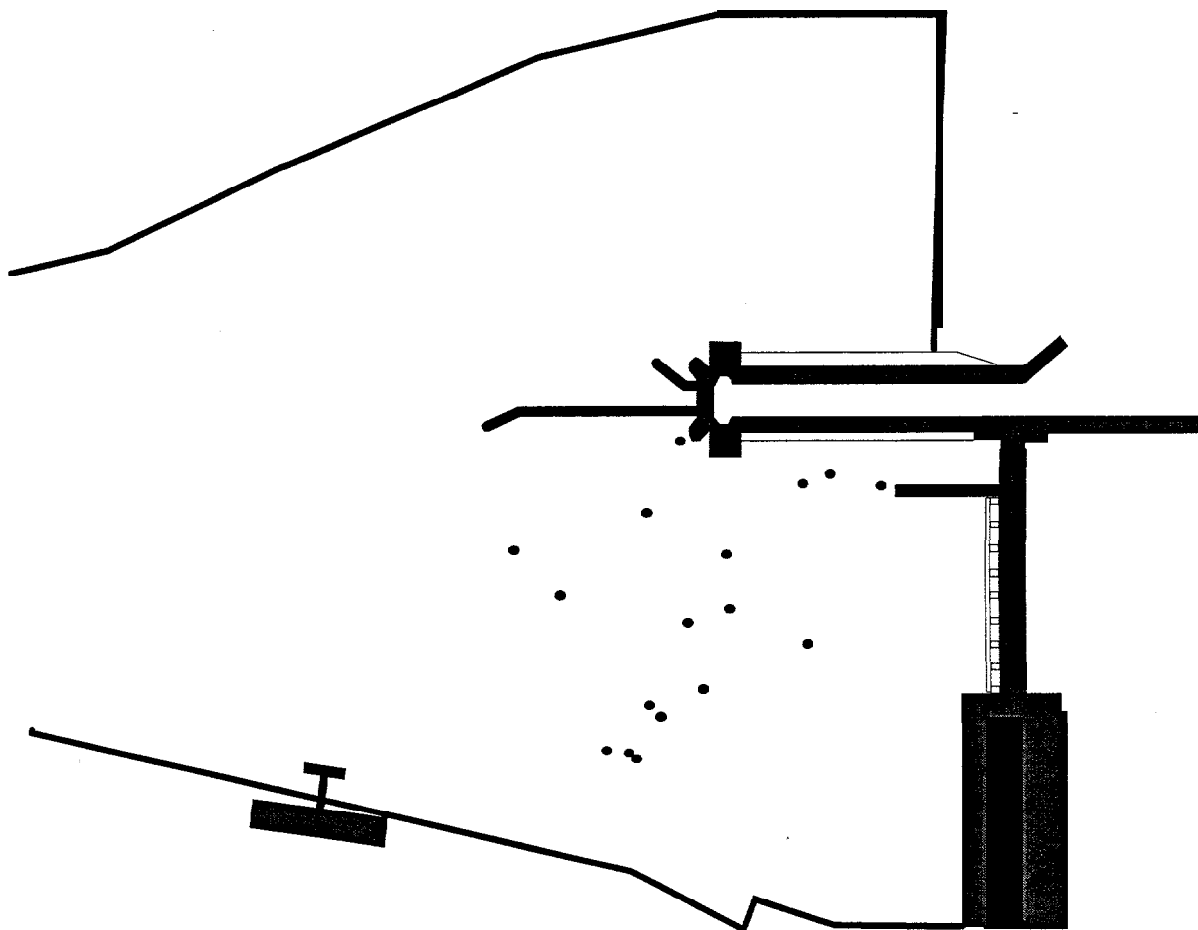
Appendix C, figure 11. Observations of northern squawfish 27-78 in the tailrace of Lower Granite Darn during the postspill period in 1993.

Appendix C, figure 12. Observations of northern squawfish 3 1-64 in the tailrace of Lower Granite Darn during the postspill period in 1993.

Appendix C, figure 13. Observations of northern squawfish 3 l-72 in the tailrace of Lower Granite Dam during the postspill period in 1993.
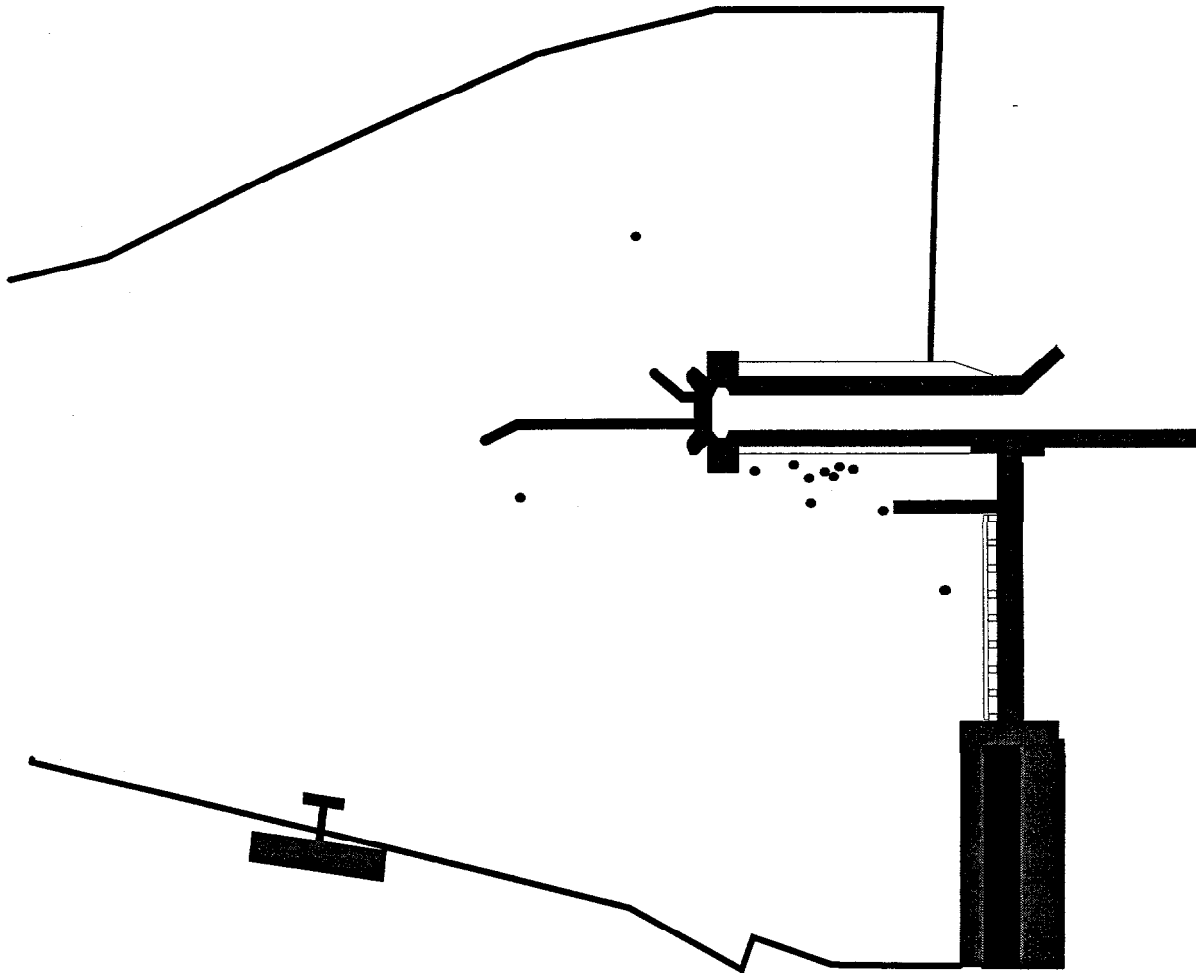
Appendix C, figure 14. Observations of northern squaw-fish 33-66 in the tailrace of Lower Granite Darn during the postspill period in 1993.

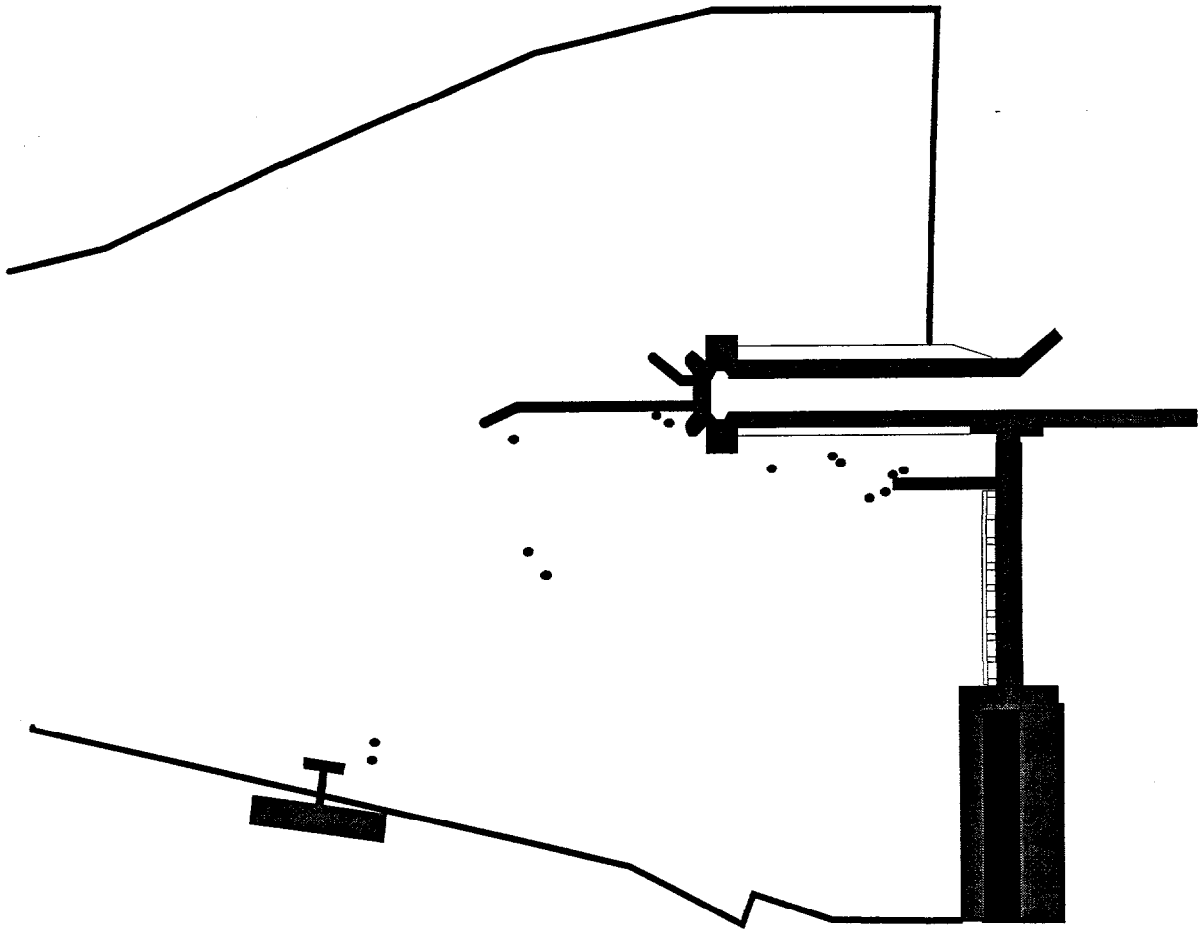Appendix C, figure 15. Observations of northern squawfish 27-74 in the tailrace of Lower Granite Dam during the postspill period in 1993.

Appendix C, figure 16. Observations of northern squawfish 32-02 in the tailrace of Lower Granite Darn during the postspill period in 1993.

Appendix C, figure 17. Observations of northern squawfish 28-78 in the tailrace of Lower Granite Dam during the postspill period in 1993.
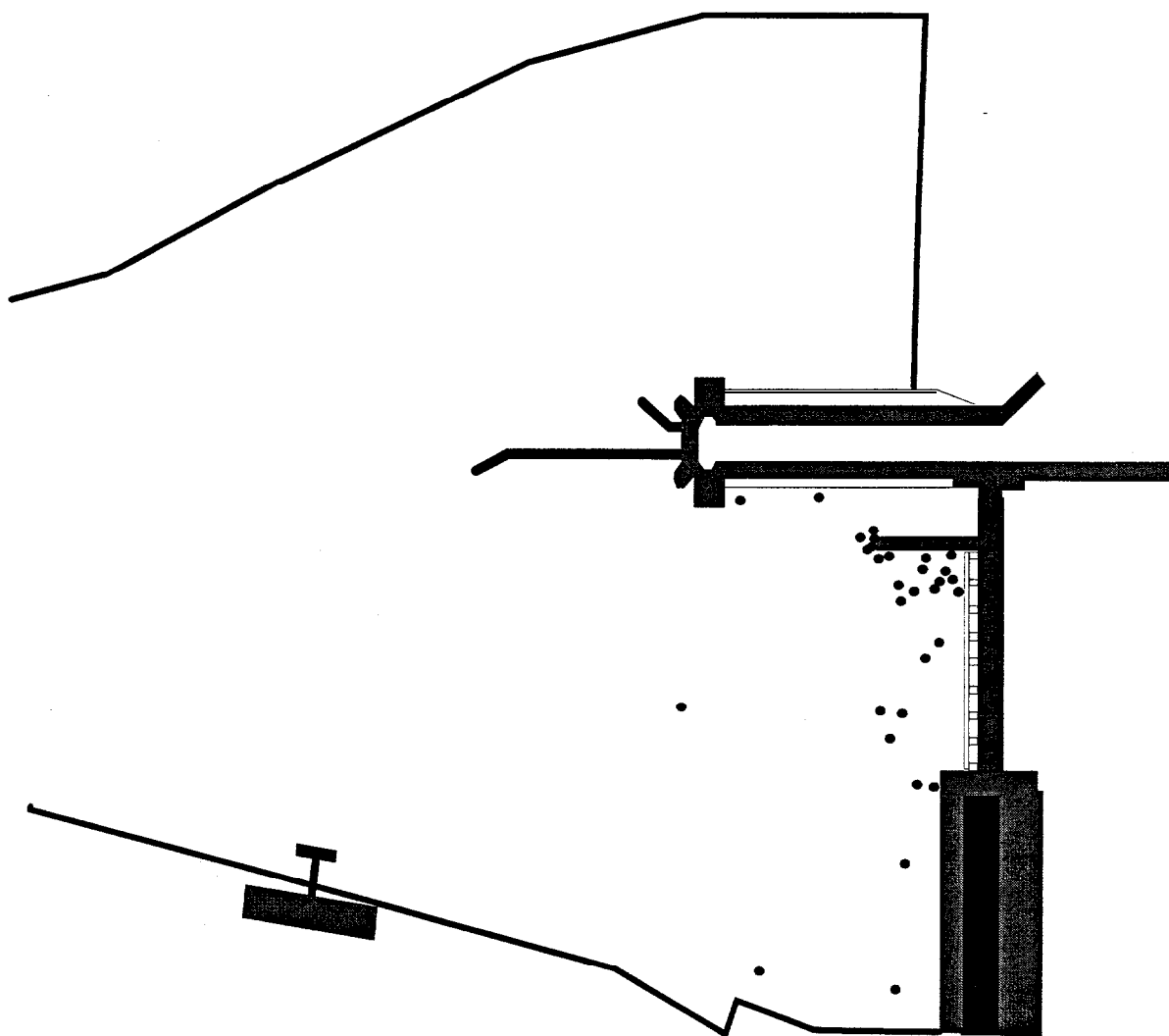
Appendix C, figure 18. Observations of northern squawfish 26-80 in the tailrace of Lower Granite Dam during the postspill period in 1993.
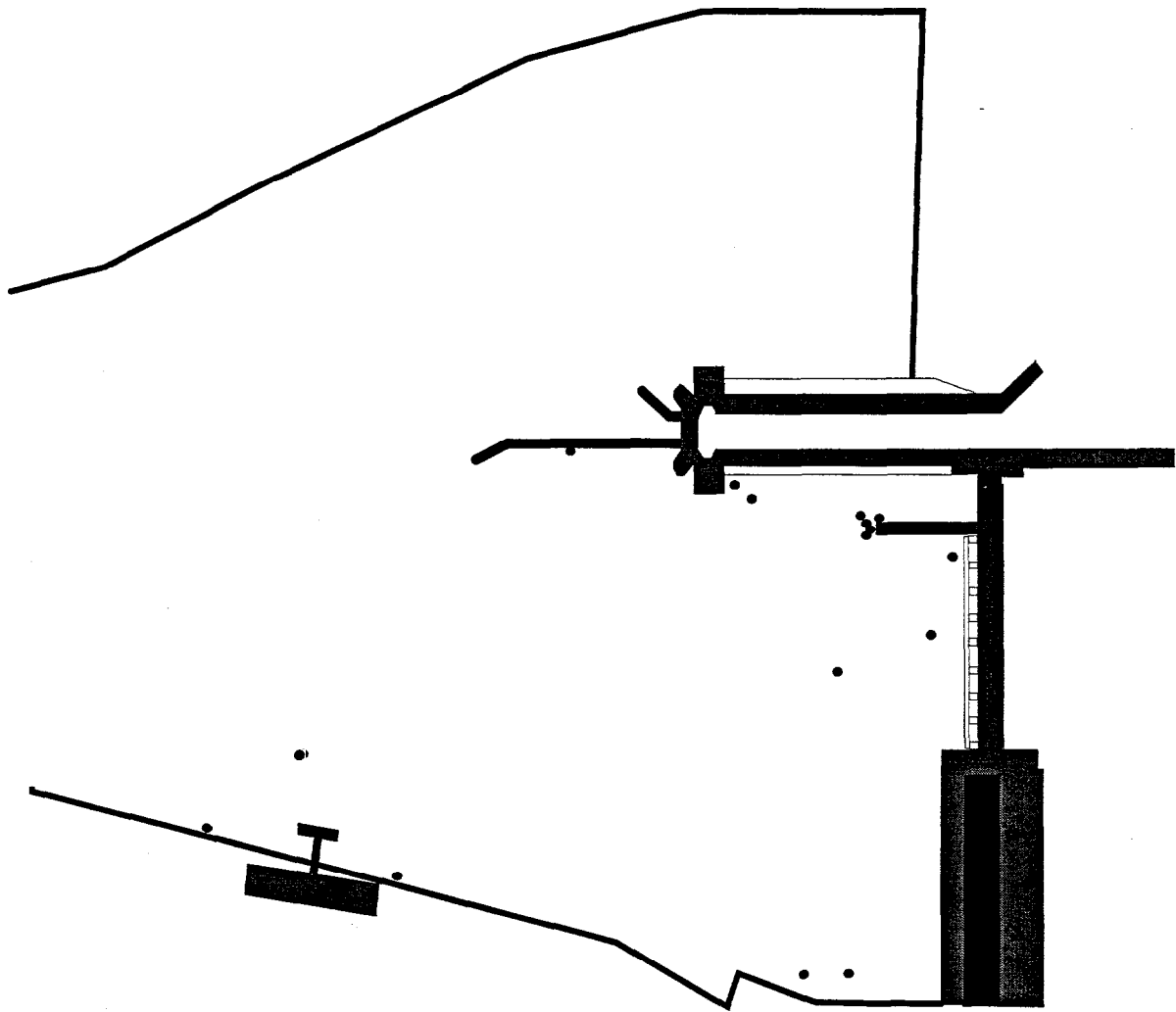
Appendix C, figure 19. Observations of northern squawfish 35-76 in the tailrace of Lower Granite Dam during the postspill period in 1993.

Appendix C, figure 20. Observations of northern squawfish 26-08 in the tailrace of Lower Granite Dam during the postspill period in 1993.

Appendix C, figure 21. Observations of northern squawfish 32-76 in the tailrace of Lower Granite Dam during the postspill period in 1993.

Appendix C, figure 22. Observations of northern squawfish 34-76 in the tailrace of
Lower Granite Dam during the postspill period in 1993.